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PRODUCTION FROM WOOD BIOMASS
IN BRITISH COLUMBIA

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IN BRITISH COLUMBIA

prepared for the

British Columbia Ministry of
Energy, Mines & Petroleum Resources
and the British Columbia
Energy Development Agency

by

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Vancouver, British Columbia

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CHAPTER 1

INTRODUCTION

The purpose of this analysis is to estimate the production costs of transportation grade methanol and ethanol manufactered in British Columbia from wood biomass feedstock sources, and to compare such costs to present and forecast prices of gasoline. Three basic study elements are involved:

(i) Estimation of site specific wood supply costs delivered to such plants.

(ii) Selection of the preferred plant technologies for the methanol and ethanol plants, and the estimation of plant capital and operating costs.

(iii) Financial analyses to determine the necessary plant gate prices of alcohol fuels to cover all production costs. Comparison of such breakeven alcohol fuel prices to present and forecast refinery prices for gasoline.

In Chapter 3, the availability and cost of wood biomass are analyzed as potential feedstock for a fuel alcohol plant in two selected regions of British Columbia. The emphasis in this analysis is on mill residuals, or hog fuel; mill residues are non-homogeneous sawmill wastes, including bark, wood debris, trim ends, sawdust, shavings and screen fines. Other potential sources of wood biomass, such as underutilized species, logging residues and yard residues, are also considered, but to a much lesser degree. As a potential biomass energy source, mill wastes are more concentrated and more readily accessible than other sources of wood biomass, which mean lower collection and transportation costs.

The assessment of methanol and ethanol process technologies and production costs, covered in Chapters 4 to 6 of the report, includes the following elements:

- assessment and selection of a wood gasifier for methanol production.
- evaluation of hydrolysis and fermentation technologies for ethanol production.
- selection of overall processes for converting wood to alcohol including equipment, material and energy balances, etc.
- estimation of plant capital and operating costs at several plant sizes.
- identification of gaps in technology.
- likelihood of successful development of alcohol plants.

Plant designs utilizing natural gas as a co-feedstock with wood residues are also evaluated. Costs are estimated at various sizes of plant to test the importance of economies of scale.

Financial analyses are undertaken in Chapter 7 for various configurations of methanol and ethanol plants. Plant gate prices are calculated which will cover all operating costs and provide the necessary return to the debt and equity capital. Sensitivity anlayses are conducted on selected plant cases to test financial performance against variations in such factors as capital and operating costs, feedstock costs, required returns to capital, debt/equity ratios, etc.

The economic viability of the plants are assessed on the basis of a discounted cash flow financial analysis related to a stand alone commercial enterprise. A more broadly based benefit/cost assessment from both the British Columbia and Canadian viewpoints is not included as part of the study. If the plant economics evaluated on a private basis look interesting, more comprehensive benefit/cost studies may be warranted to determine the degree of public support that would be warranted.

The estimation of distribution costs from plant location to retail outlet and fuel utilization costs in terms of vehicle modifications that would be associated with alcohol fuels are not included within the terms of reference of this study. If the production costs of alcohol fuels estimated here appear potentially attractive further analysis will be warranted to establish reliable estimates of such distribution and fuel utilization costs.

This report is a joint effort of three consulting companies. McDaniels Research Ltd. undertook the wood supply analysis in Chapter 3. The technical assessment of ethanol and methanol plants in Chapters 4, 5 and 6 was done by B.H. Levelton and Associates Ltd. The financial analysis work in Chapter 7, and the overall report co-ordination, was performed by Canadian Resourcecon Ltd.

CHAPTER 2

SUMMARY AND CONCLUSIONS

2.1 Wood Supply Costs

Previous studies have indicated that the costs of biomass feedstocks are likely to be one of the most important parameters affecting the financial returns of potential alcohol fuel production facilities. Equally significant is that the volume of biomass material available in one location is the chief determinant of the scale of an alcohol fuel plant. Both these points suggest that a thorough assessment of wood biomass costs and availability is a crucial step in the evaluation of an alcohol fuel production facility.

The analysis of wood supply costs presented in Chapter 3 is predominantly concerned with sawmill wastes, or hog fuel. Emphasis is placed on sawmill residues because the British Columbia Interior forest industry produces huge amounts of mill wastes that are surplus to industry requirements, and now pose significant disposal problems. Moreover, mill residues are typically at least partially processed, and are concentrated at forest industry centres in accessible locations around the province, meaning their collection and transportation costs are far lower than most other forms of forest biomass. Other potential sources of wood biomass, such as logging residues or sortyard debris, are also considered in Chapter 3, but only to a limited extent.

Chapter 3 provides data regarding the cost and availability of mill residues in two regions in British Columbia. One region, Williams Lake, was selected because it contains one of the province's largest concentrations of mill residue production in a central location. The second region, Kamloops, was selected because it contains large volumes of mill residuals dispersed over a wide area in various conversion centres. The Williams Lake situation can be taken to represent the lowest cost concentration of wood biomass in the province, if not in Canada, while the Kamloops situation represents a higher cost but still potentially attractive case. In terms of cost, the chief difference between these two cases is the effect of transportation on overall supply costs.

The general approach of Chapter 3 begins with estimates of current mill residuals production provided by forest industry sources in the two regions. Then scenarios are developed regarding future alternative uses of mill residues for both energy and fibre purposes in these regions. The chapter conservatively assumes that any wood wastes which could potentially be utilized for any alternative purposes are unavailable for an alcohol fuel plant.

Briefly, the long-term supply and cost estimates for wood residues in the two regions can be summarized as shown below:

Location	Quantity	Supply Cost (1982$)
Williams Lake	350,000 ODt/yr (local) 250,000 ODt/yr (from Quesnel)	$ 4/ODt $14/ODt
Kamloops	350,000 ODt/yr	$29/ODt

These wood supply costs, delivered to the plants, consider both transportation and handling costs, but make no specific allowance for opportunity costs, since the available material is assumed to have no alternative uses.

It should be stressed that these results are highly conservative, in that they tend to overestimate costs and underestimate volumes. For example, no credits for avoided disposal costs are considered; such credits could conceivably lower supply costs at Williams Lake by at least $1/ODt, and considerably more at Kamloops. Similarly, the estimates are very conservative in terms of the volumes of material assumed to be available for alcohol conversion. At Kamloops, for example, the figures assume that only bark is available for alcohol feedstock, implying that all other components of the residue stream would in the future be required for other uses. At Williams Lake, the data assume that wood wastes would replace natural gas in local lumber kilns, and also that all chippable material is recovered for fibre uses.

Even with these highly conservative assumptions, the results show that vast quantities of very low cost feedstock are available for alcohol conversion in the British Columbia Interior. It seems likely that the Williams Lake region, supplemented with supplies from Quesnel, contains the largest concentration of high quality, low cost energy biomass in Canada. If the assumptions adopted here should in the future prove to be overly conservative, the volumes available at the estimated cost would be even greater.

It should be noted that there are likely to be a few other locations in the provincial Interior with wood residue costs comparable to those at Williams Lake, although perhaps not with as large a volume. Similarly, there are likely to be at least five other regions with costs and volumes of mills residuals comparable to those estimated for Kamloops.

2.2 Plant Design and Costs

(a) Methanol Plant Processes

To use a wood feedstock for methanol production a gasification process is needed to produce a gas which is rich in the desired synthesis gases, and that can be cleaned and upgraded to essentially the same quality as the synthesis gas produced from natural gas. Several gasification processes appropriate for this are under development but none are yet commercially applied. Technology for cleaning and modification of a synthesis gas derived from wood and for conversion of this gas to fuel or chemical-grade methanol is commercially available and well proven in comparable applications, such as chemical plants using coal, natural gas, and petroleum feedstocks.

At present, there are not any methanol plants operating with a wood feedstock.

This study concentrates on near-commercial technologies for the production of methanol from wood. Due to the large number of gasification systems under development for wood and the lack of commercial operating experience for any gasifiers producing synthesis gas, only those gasifiers deemed to be of near-commercial status and having performance characteristics that are attractive for methanol production were considered as possible candidates. From these candidates, the Wright-Malta steam gasification process is chosen for the final cost analysis. This system is deemed to be of near-commercial status and has performance characteristics that are attractive for methanol production.

Presently, the Wright-Malta process requires minimal feedstock preparation compared to alternative fluidized-bed oxygen- and steam-blown gasification processes. The greater amount of feedstock preparation of some of these alternatives may prove to be counterbalanced by improved gasifier performance, such as steadier operation, improved gas yields, lower tar and oil yields, etc. However, there are presently insufficient data to clearly identify the best of the many gasifier alternatives.

Methanol plants with 300 tonne/day and 600 tonne/day methanol capacities utilizing wood feedstock are evaluated in this study. Also studied is a plant of 990 tonne/day capacity utilizing a combination of natural gas and wood as feedstock. It is assumed that the wood feedstock consists of hogged wood and bark. The gasifier performance is fairly insensitive to the bark content of the feed.

Two concepts are considered for a hybrid wood/methane feedstock plant. The optimistic case assumes that the synthesis gas from wood gasification is mixed directly with natural gas after gas cleanup, then this gas is reformed. The acid gas removal step in this case is no longer needed. The pessimistic case assumes that the wood-to-methanol and natural gas-to-methanol trains operate independently with a transfer of hydrogen from the natural gas-fed to the wood-fed trains. Both cases assume a wood gasification rate equal to that used for the base case 300 t/d methanol plant. Capital and operating costs are developed for both cases and are expected to cover the possible cost range. The financial feasibility analysis conducted in this report for the wood/natural gas case is based on the high cost plant alternative.

Fuel grade methanol is the product being produced. The minimum methanol content is 99.5 percent; the product will also contain acetone and aldehydes as well as small amounts of water.

(b) Ethanol Plant Processes

The main process units for an ethanol plant are:

- hydrolysis;
- fermentation;
- separation of ethanol.

The balance of the plant consists of facilities for steam and power generation, process water supply, waste water treatment, by-products processing, and general service.

Selection of the method of hydrolysis is a critical decision for design of a plant producing ethanol from wood. The remaining processing steps have been well proven with other feedstocks and are expected to be readily transferable. No commercial experience with wood hydrolysis has been gained in recent years in the Western World. Acid hydrolysis is presently considered to be the only viable choice for commercial application in the near future. Enzymatic hydrolysis has not been tested at a pilot scale, and consequently, commercialization is some time away.

Of the several acid hydrolysis processes under development for wood feedstocks the dilute sulfuric acid processes has received the most attention. Dilute sulfuric acid hydrolysis systems for wood are presently being proposed for commercial applications by Inventa AG of Zurich, Switzerland, and the New Zealand Forest Research Institute. Inventa markets a process based on the earlier Scholler hydrolysis process while the New Zealand Research Institute markets a modified Madison process.

The Inventa Process appears to be nearest to commercialization, based on experience gained with a pilot plant operated with a wood feedstock, company experience with similar chemical plants, and company preparedness for marketing. Inventa is presently marketing turn-key plants for wood feedstocks worldwide, although no commercial plants are currently operating. Studies of application of the process in North America have been performed by Inventa's agent, Pedco of Cincinatti (Pedco International Inc.).

Plants with 150 tonne/day and 300 tonne/day ethanol capacities are evaluated in this report. The 300 t/d plant is studied for cases both with and without by-product values. The chemical furfural can be upgraded during hydrolysis to a commercial product by further processing. Other by-product credits which are considered in this case are from the co-production of gypsum and small quantities of methanol.

Near-commercial acid-hydrolysis plants can only accept a feedstock containing a very small amount of bark; the upper limit on bark content has not been clearly defined by any current suppliers. Ethanol production will depend on an adequate supply of suitable wood feedstock being available at the sites considered in this study at the estimated costs. In fact, the production of ethanol may not be possible at many potential sites because of a lack of high quality feedstock.

(c) Plant Configurations

The plant sizes which are evaluated were largely determined based on the availability of wood feedstock at the Williams Lake and Kamloops sites. The cases which are analyzed are the following:

Plant Sizes Evaluated

Case 1	Product	Plant Size		Location
1.	ethanol	150 t/d	without by-product	Williams Lake
2.	ethanol	150 t/d	without by-product	Kamloops
3.	ethanol	300 t/d	with by-products	Williams Lake
4.	ethanol	300 t/d	without by-products	Williams Lake
5.	methanol	300 t/d		Williams Lake
6.	methanol	300 t/d		Kamloops
7.	methanol	600 t/d		Williams Lake
8.	methanol	990 t/d	wood/natural gas	Williams Lake

As may be noted, six of the eight cases are based on the Williams Lake site where the wood feedstock is cheaper and more plentiful. Two cases are considered at a Kamloops site to test the sensitivity of total production costs to the cost of feedstock. All other production and operating costs are considered equal at both locations.

In the Williams Lake area, the supply of total residues or wood would only be adequate for both the 150 t/d ethanol plant and the 300 t/d methanol plant. Because of the requirement for fairly bark-free wood feedstock, the supply of feedstock in the Williams Lake area may not be adequate for a 600 t/d ethanol plant over the long term, although this is presently somewhat uncertain. Supplies would probably be adequate for a 600 t/d methanol plant, primarily because of the insensitivity of the process to the bark content of the feed.

The higher bark content of the residues available in the Kamloops area poses a problem for supply of feedstock having a suitable quality for a 300 t/d ethanol plant. Supplies may be adequate for a 150 t/d ethanol plant, but presently-identified supplies are principly bark, and thus of inferior quality. Biomass supplies in this area are adequate for both the 300 and 600 t/d methanol plants.

(d) Plant Capital and Operating Costs

Plant capital and operating costs, not including feedstock costs, which are detailed in Chapters 5 and 6 are summarized as follows:

Case #		Cap. Cost	Op. Cost	Feedstock Requirement	
		(million 1982$)		Wood (000 ODt/yr)	N. Gas PJ/yr
1,2	150 t/d ethanol without by products	96	16	248	---
3	300 t/d ethanol with by products	217	20	495	---
4	300 t/d ethanol without by products	143	26	495	---
5,6	300 t/d methanol	79	12	239	---
7	600 t/d methanol	124	20	478	---
8	990 t/d methanol	150	23	239	4.56

2.3 Financial Analysis

Plant gate prices are developed for methanol and ethanol, which are sufficient to cover all costs of production, including feedstock costs, operating costs and specified returns to capital. These prices are then compared to forecast gasoline prices for both a high crude oil price forecast case and a low crude oil price forecast case.

(a) High Crude Oil Price Forecast Case

The Canadian crude oil price is forecast based on a world price which is forecast to increase, in real terms, at an average annual rate of 2% per year to 2000 (see Table 7-3). The refinery gasoline price in British Columbia related to this crude oil price is forecast to increase from 29¢/l in 1982 (1982 $) to some 52¢/l in 2000 (1982 $) (Table 7-4).

Table 2-1 and Table 2-1A compare the calculated methanol and ethanol plant gate prices to the forecast gasoline prices. The price of methanol produced by either the 600 t/d wood plant or the 900 t/d wood/natural gas plant at Williams Lake compares favourably to the refinery gasoline price.

The sensitivity of methanol and ethanol plant financial feasibility to variations in a number of economic parameters is tested in the study. The results of the sensitivity runs are summarized in Table 2-2. Though the sensitivity of the alcohol fuel plant gate prices to variations in the wood feedstock cost is small at Williams Lake, reflecting the fact that wood costs at this price ($4/ODt) are only a small part of total costs, it is clear that wide swings in wood supply costs would be more important. This is illustrated by the difference of nearly 5¢/l in the breakeven price of methanol in the 300 t/d plant case between the Williams Lake location ($4/ODt) and the Kamloops location ($29/ODt) (see Table 7-1).

The sensitivity of the breakeven prices to capital and operating cost changes in the hybrid gas/wood case is less than for the wood plants at Williams Lake; this is due to the much greater relative importance of the natural gas feedstock cost ($3.26/GJ in 1982), on an energy content

TABLE 2-1

REFINERY GATE COMPARISONS OF GASOLINE, METHANOL AND ETHANOL

HIGH GASOLINE PRICE FORECAST CASE

(1982$/GJ)

	Gasoline	Methanol		Ethanol
		600 t/d	990 t/d	
1986	10.66	11.11	11.06	20.94
1987	10.95	11.11	11.06	20.94
1988	11.27	11.11	11.06	20.94
1989	11.59	11.11	11.06	20.94
1990	11.90	11.11	11.06	20.94
1995	13.40	11.11	11.06	20.94
2000	14.90	11.11	11.06	20.94

SOURCE: Table 7-5.

NOTE: For the alcohols, these are levellized prices which remain constant over time in real dollar terms and give the required return on investment.

TABLE 2-1A

REFINERY GATE COMPARISONS OF GASOLINE, METHANOL AND ETHANOL

HIGH GASOLINE PRICE FORECAST CASE

(1982$/GJ)

	Gasoline	Methanol		Ethanol
		600 t/d	990 t/d	300 t/d
1986	10.66	9.73	9.66	18.50
1987	10.95	10.00	9.92	19.00
1988	11.27	10.29	10.21	19.55
1989	11.59	10.58	10.50	20.10
1990	11.90	10.87	10.78	20.66
1991	12.18	11.13	11.04	21.16
1992	12.47	11.39	11.31	21.66
1993	12.76	11.66	11.57	22.16
1994	13.07	11.94	11.86	22.70
- 1995	13.40	12.23	12.14	23.25
1996	13.68	12.50	12.41	23.75
1997	13.97	12.76	12.67	24.25
1998	14.29	13.05	12.96	24.81
1999	14.58	13.32	13.22	25.31
- 2000	14.90	13.60	13.50	25.85

SOURCE: Table 7-5A

NOTE: For the alcohols, these are prices calculated at a constant percentage relationship to the gasoline price which give the required return on investment.

TABLE 2-2

SUMMARY OF SENSITIVITY ANALYSES

WILLIAMS LAKE LOCATION

	300 t/d Ethanol Without By-Product Unit Revenue 1982 ¢/l			600 t/d Methanol Unit Revenue 1982 ¢/l			990 t/d Methanol Unit Revenue 1982 ¢/l		
	Base Case	Sensitivity Case	Change	Base Case	Sensitivity Case	Change	Base Case	Sensitivity Case	% Change
A) 25% increase in K, O&M costs	48.6	60.0	+23.4	20.0	24.6	+23.0	19.9	23.2	+16.6
B) 25% decrease in K, O&M costs	48.6	37.2	-23.4	20.0	15.3	-23.5	19.9	16.5	-17.1
C) increase in equity from 50% to 100%	48.6	53.4	+9.4	20.0	22.1	+10.5	19.9	21.5	+8.0
D) decrease in equity from 50% to 0%	48.6	45.6	-6.2	20.0	18.7	-6.5	19.9	18.9	-5.0
E) increase in cost of debt & return on equity by 5%	48.6	54.8	+12.8	20.0	22.7	+13.5	19.9	21.7	+9.0
F) decrease in cost of debt & return on equity by 5%	48.6	43.3	-10.9	20.0	17.6	-12.0	19.9	18.3	-8.0
G) zero real K, O&M escalation	48.6	43.5	-10.5	20.0	18.0	-10.0	19.9	18.4	-7.5
H) 50% increase in feedstock cost	48.6	50.1	+3.1	20.0	20.7	+3.5	19.9	23.0	+15.6
I) 50% decrease in feedstock cost	48.6	47.1	-3.1	20.0	19.3	-3.5	19.9	17.0	-14.6

SOURCE: Canadian Resourcecon Ltd.

basis, in the wood/gas plant compared to the wood feedstock cost in the wood only plant ($4/ODt = $0.20/GJ).

(b) Low Crude Oil Price Forecast Case

The Canadian crude oil price (Table 7-8) is forecast in relation to a world price which declines 10% in 1983 in current dollars, and then remains at that level through 1985; from 1985 to 1990 the world price increases at the rate of inflation, and from 1990 to 2000 at a rate 1% per year greater than the rate of inflation. The British Columbia gasoline price on this basis declines in real terms from 29¢/l in 1982 (1982 $) to 25.5¢/l by 1985; its forecast price of 27.8¢/l (1982 $) in 2000 is lower than the 1982 price.

Table 2-3 compares this gasoline price forecast to the plant gate prices of methanol for the 600 t/d and 990 t/d plants at Williams Lake. In this case, the price of methanol produced from the 600 t/d plant is appreciably higher than the forecast gasoline price. The 990 t/d wood/natural gas plant produces methanol which is considerably cheaper in this case ($9.45/GJ) than in the high oil price case ($11.06/GJ) due to the much lower associated natural gas feedstock cost; this methanol price is still, however, higher than the forecast gasoline price of $7.35/GJ to $8.01/GJ.

2.4 Conclusions

(a) Methanol Plant

Wood gasification must be demonstrated at a scale of about 250 ODt/d before any attempted development of commercial methanol plants for wood feedstock. This is needed because of the lack of experience of the present developers with gasifiers of size that adequately demonstrates the performance of the unit under continuous operation. The operation of this demonstration unit must be monitored in sufficient detail to refine the gasifier design so that it yields a

TABLE 2-3

REFINERY GATE COMPARISONS OF GASOLINE AND METHANOL PRICES
1986 - 2000

LOW CRUDE OIL AND NATURAL GAS
PRICE FORECAST CASE

(1982$/GJ)

	Gasoline(1)	Methanol	
		600 t/d(2)	990 t/d(3)
1986	7.35	11.10	9.45
1987	7.35	11.10	9.45
1988	7.35	11.10	9.45
1989	7.35	11.10	9.45
1990	7.35	11.10	9.45
1995	7.67	11.10	9.45
2000	8.01	11.10	9.45

SOURCE: Table 7-11.

NOTE: For methanol, these are levellized prices which remain constant over time in real dollar terms and give the required return on capital.

synthesis gas that is satisfactory for further chemical processing to methanol. Trial runs should also be made using batch samples of the gas in a methanol-synthesis train to quantify product yields. Several suppliers of methanol synthesis technology have process equipment that could be used for this purpose.

Either steam or oxygen may be used to gasify wood and yield a synthesis gas that may be converted to methanol with established chemical processing technologies. In this study, steam gasification using the Wright-Malta process was chosen since it has several advantages over the oxygen gasification approach. These advantages are:

- no need for an oxygen separation plant;
- the process operates at elevated pressure and has been demonstrated at a small scale;
- the process can accept wet, coarse wood residues;
- potentiall higher plant efficiency;
- potentially lower product cost.

The last two of these advantages are somewhat uncertain since they have been found only from feasibility studies, and not from operating experience or detailed plant designs. The differences between plant efficiency and product cost for the steam and oxygen approaches are small considering the uncertainty in the plant design and cost, and may change as development of these processes proceeds. More work would be needed to determine whether steam or oxygen gasification is the best gasification process. Results to date show that both processes would be able to produce a synthesis gas of acceptable quality for methanol production.

(b) Ethanol Plant

For production of ethanol from wood, two approaches are being tried;

one being acid hydrolysis, the other being enzymatic hydrolysis. Only acid hydrolysis is considered to be at a near-commercial level of development. The acid hydrolysis-based process developed and marketed by Inventa was selected for this study because of the experience of the company with past production of ethanol from wood, and their state of preparation for commercialization. The main limitation of the technology for ethanol production from wood, including the Inventa process, is the requirement for a feedstock low in bark content. Inventa presently recommends use of white wood feedstocks, or ones very low in bark content, since these are the feedstocks that have been most thoroughly tested. Insufficient testing has been conducted with feedstocks containing bark to know what effect bark has on the hydrolysis and fermentation processes and, ultimately, on ethanol yield.

Because of the high bark content of the wood feedstocks available in both Kamloops and Williams Lake, batch tests with an ethanol pilot unit, such as available at Inventa, would be needed before a more detailed evaluation of the feasibility of an ethanol plant at these sites could proceed.

(c) Economic Studies

This study concludes that methanol produced from wood biomass sources in British Columbia may be an attractive transportation fuel compared to gasoline (based on the high crude oil price forecast case). As a result, it is recommended that further study be undertaken to establish reliable estimates of methanol distribution and utilization costs to determine if "in use" price comparisons between methanol and gasoline are equally favorable.

A benefit/cost assessment of methanol produced from wood biomass should also be undertaken, from both a British Columbia and a Canada perspective. This would help to determine the degree of public support that would be justified in encouraging the development of such an enterprise in British Columbia.

(d) Fuel Production Quantities

On a volume basis, the quantities of fuel grade methanol produced from a wood biomass plant will be small compared to total gasoline demands. Total consumption of gasoline in British Columbia in 1981 was 7,436 x 10^6 litres. The output of methanol from the 990 t/d plant analyzed here would be some 413 x 10^6 l/yr; this is 5.5% of B.C.'s 1981 gasoline consumption on a volume basis, and 2.9% on an energy content basis.

Ethanol quantities of 125 x 10^6 litres per year (300 t/d plant) would account for about 1% of gasoline consumption on an energy basis.

CHAPTER 3 - WOOD SUPPLY COSTS

3.1 Introduction

(a) Overview

In this chapter, the availability and cost of wood biomass are analyzed as potential feedstock for a fuel alcohol plant in two selected regions of British Columbia. The emphasis in this analysis is on mill residuals, or hog fuel; mill residues are non-homogenous sawmill wastes, including bark, wood debris, trim ends, sawdust, shavings and screen fines. Other potential sources of wood biomass, such as underutilized species, logging residues and yard residues, are also considered, but to a much lesser degree. Priority is placed on mill residuals because they are in abundant supply, and not currently utilized in most interior regions of British Columbia, and at present require costs for disposal. As a potential biomass energy source, mill wastes are more concentrated and more readily accessible than other sources of wood biomass, which mean lower collection and transportation costs.

Supplies and costs of mill residuals are examined for two regions. Williams Lake is considered first, because it has large volumes of surplus mill residuals concentrated within a centralized area. The Kamloops region is reviewed second; it contains large volumes of surplus mill residues dispersed over a wider area in regional centres. The major difference in these two case studies is the effect of transportation on overall supply costs.

(b) Study Objectives and Approach

As outlined in the proposal, the specific objectives of this study are:

- the identification of potential sites;
- detailed supply and cost analysis;
- analysis of opportunity costs;
- analysis of long-term supply for biomass;
- analysis of associated benefits.

Our approach to each of these objectives is briefly outlined below.

(i) Identification of Potential Sites

Several criteria were considered in selecting potential sites for detailed analysis of wood biomass supply. The primary criterion was the potential availability of surplus hog fuel; preliminary information on this topic was obtained from the Reid, Collins and Associates Ltd. (1978) study entitled "Hog Fuel Availability in British Columbia", prepared for the Wood Waste Energy Co-ordinating Committee. In that study, hog fuel surpluses were identified for regions with single supply centres or with several supply centres. The centre with the largest concentrated surplus of hog fuel was identified as Williams Lake. Similarly, Kamloops region was identified as having the largest hog fuel surplus dispersed over a number of regional centres.

Another criterion in site selection was: the need for a community of at least 10,000, serviced with a natural gas line and rail facilities. Both Williams Lake and Kamloops satisfied this criterion.

(ii) Detailed Supply and Cost Analysis

The initial step in our detailed analysis of mill residual supplies involved verification of the assumptions and approach implicit in the wood waste volume estimates of the Reid, Collins (1978) study. Interviews were conducted with Ministry of Forests' personnel in Victoria and in the Cariboo and Kamloops regional offices. In these interviews, general agreement was expressed with the methods Reid, Collins used to estimate hog fuel surplus volumes; moreover, the interviewees indicated that no appreciable change had occurred in the log consumption and conversion factors adopted in the

Reid, Collins (1978) study.[1]

Early in the interview phase, it became apparent that a direct, detailed survey of all mill residual producers and consumers would be unlikely to improve upon the existing information contained in the Reid, Collins study. Often, mill operators do not keep track of actual mill residual production, especially where on-site burners are used to dispose of mill wastes.

Rather than indirectly derive mill residual volume estimates by re-employing the Reid, Collins approach, aggregate estimates were obtained from industry sources in both regions. In Williams Lake, estimates were obtained from an engineering study commissioned by an ad hoc "burner committee" of the five major operators in the area.[2] In Kamloops, estimates of regional mill residual surpluses were provided by Weyerhaeuser Canada Ltd., currently the only significant purchaser of mill residuals in the Kamloops area.

Cost estimates of collecting and transporting residues were based on the operating costs experienced by existing purchasers of hog fuel in both regions, namely Cariboo Pulp and Paper Ltd., in the Cariboo Forest Region, and Weyerhaeuser Canada Ltd., in the Kamloops Forest Region.

(iii) Analysis of Opportunity Costs

The opportunity cost, or market value of mill residuals to producers, is a function of existing and potential uses for mill residuals. These primarily include fibre and energy applications within the forest industry, and possibly, energy applications outside the forest industry. The current situation, with excess supplies of mill residuals, involves negative opportunity costs to producers due to the need for disposal. However, this situation may change in the future; increased use of residues in the forest industry is a strong possibility.

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(1) See Appendix A for list of interviewees.

(2) These include Jacobson Bros. Forest Products Ltd., Weldwood of Canada Ltd. (Merrill and Wagner Operations), Pinnette and Therrien Mills Ltd., Lignum Ltd., and West Fraser Forest Products Ltd.

In order to determine the economically optimum pattern of use for mill residues, major modelling studies would be required. Neither the resources nor the data were available for such analysis. Instead the approach adopted was to develop scenarios of potential alternative uses of residues in each region. The quantities of residues not required for other uses were assumed to be available for alcohol conversion. Implicit in this approach is the conservative assumption that other potential uses have opportunity values which exceed the amount an alcohol plant could afford to pay for feedstock.

(iv) Analysis of Long-Term Supply for Biomass

Long-term mill residuals supply depends upon the level of timber harvest and the utilization of logs and mill residuals in processing. Factors affecting harvest volumes and log utilization are considered over a 20 year period, the short-term planning period used by the Ministry of Forests in assessing the timber resource capabilities within Timber Supply Areas. Projections of harvest are based on Timber Supply Area reports for Crown timber in each region.

(v) Analysis of Associated Benefits

A primary benefit in the utilization of mill residuals is the reduction or elimination of existing costs of disposal now incurred by mill operators and in the environmental costs of air pollution. For each area, estimates are provided of current costs of disposal. No evaluation is made of the benefits of reducing environmental costs from current mill residue disposal practises, since this issue entails major surveys which are beyond the scope of this study.

3.2 Mill Residuals: Supply and Demand Issues

Briefly outlined in this section are general issues affecting the availability and cost of mill residuals in British Columbia.

(a) Supply of Mill Residuals

(i) Supply Determinants

Mill residuals are an involuntary by-product of timber production. The level of timber harvest and the percentage recovery of finished products from log inputs are, therefore, critical factors in the overall supply of mill residuals. In most forest regions in British Columbia, and particularly in the two study areas, the current level of Crown timber harvest is close to the regulated annual allowable cut. The volume of mill residuals generated from Crown timber production is thus broadly limited to current production levels.

Milling efficiency in recovering lumber, chips and other forest products from log input is the other critical determinant of residuals production. A number of improvements in milling technology have in the past improved recovery factors, consequently reducing the volumes of mill residuals. In general, these improvements in recovery factors require high technology equipment with large capital costs.

Improved product recovery standards may, over time, change both the composition and total volume of residuals supply. Tighter cutting patterns, narrow kerf sawblades and refinements in planing are expected to reduce the volumes of sawdust and shaving residuals. Other improvements such as finger-joint stud mills that utilize end pieces otherwise directed to chip production or residuals are also possible. Although these improvements could reduce the total volume of residues, there should still be considerable quantities available for energy purposes. The largest components of the mill waste stream are bark and other material unsuitable for fibre use.

(ii) Supply Variations

The chief factor affecting the consistency in production of mill residuals is the consistency of timber harvest. Forest product markets, both lumber and pulp, are subject to wide fluctuations in demand. Such variations could potentially mean that large variations occur in the supplies of mill residues for an alcohol conversion plant. This issue is discussed at great length in section 3.5 of this chapter.

In British Columbia, the influence of demand fluctuations is somewhat dampened by the system of Crown charges for timber and timber management practices in British Columbia. Simply stated, the basis for, and method of Crown timber pricing is as follows:

> Standing timber derives its commercial value from its convertibility into saleable products at a profit. The value of standing timber is the difference between sales value of the marketable "end products", and the costs of manufacturing and marketing those products including a margin for profit and risk. (B.C. Ministry of Forests, 1980b)

Fluctuations in forest product market prices are borne to a certain extent in Crown charges for timber. When product markets are bouyant, Crown charges for timber are high; when markets are depressed, Crown charges for timber are low.

The design and ultimate effect of this system is to provide output and hence employment stability for the industry. As a result of relative production stability, there is greater consistency in the production of mill residuals. The consistency and trends in British Columbia timber harvest in recent years is shown in Table 3-1.

(b) Demands for Mill Residuals

(i) Forest Industry Applications

Fibre and energy applications are the two predominant uses for mill residuals in the forest industry. These options are assessed in detail in a Canadian Forestry Service report by McDaniels Research Ltd. (1981). Briefly, the fibre demands include residuals used as pulp furnish or in particle board. Energy applications for mill residuals within the forest industry include fuel for kiln dryers and plant heat in sawmills and veneer plants and fuel for power boilers in pulp mills.

TABLE 3-1

TOTAL AMOUNT OF TIMBER SCALE BILLED IN BRITISH COLUMBIA: BY FOREST REGION

m^3 per annum

Forest Region	Ten Year Average 1970-1979	1978	1979	1980
Cariboo	4,327,227	7,469,233	6,503,757	6,948,601
Kamloops	8,070,303	8,908,157	8,812,840	8,519,126
Nelson	5,129,083	7,254,651	6,903,662	6,566,205
Prince George	12,220,468	13,927,056	15,984,819	14,201,377
Prince Rupert	8,945,123	9,403,502	11,526,934	12,611,624
Vancouver	24,201,810	28,190,485	26,462,067	25,807,343
Totals	63,894,019	75,173,084	76,194,079	74,654,276

SOURCE: B.C. Ministry of Forests, 1980a, 1979a.

Fibre Use

Currently, fibre demands for mill residuals are limited to a small portion of the cleaner components of total mill residuals. One pulp mill with a sawdust digestor utilizes sawdust and shavings as pulp furnish, but this use is limited. Because of the smaller fibre size, pulp from sawdust is blended with pulp from wood chips to obtain a uniform product. Generally, as the proportion of sawdust increases the quality of pulp decreases, thus the economics of sawdust pulping must be weighed against the resultant reduction in pulp quality. Increased demands for sawdust for pulping depend upon increased pulping capacity, specifically in the addition of sawdust digestors.

In general, one can state that use of cleaner mill residues for pulp will not increase dramatically until the excess supplies of chips are fully utilized in the province, since chips can be used at lower cost and produce a higher quality product.[1]

Another fibre use is the demand for sawdust and shavings in particle board. Particle board production is expected to expand only gradually and is not expected to significantly reduce the overall availability of residuals for energy uses (McDaniels, 1981).

Energy Use

Use of residues for energy purposes in the forest industry is already substantial, and has the economic potential to increase significantly. In sawmills and veneer plants, mill residuals can potentially be used to fired kiln dryers and provide plant heat. Due to their relative dryness and ease of handling, sawdust and shavings are generally favoured over bark and mixed hog fuel by sawmills. However, bark has a higher energy value than sawdust and shavings. Factors such as the relative price of natural gas and the capital costs of conversion are the chief determinants of increased wood energy utilization in the wood products sector.

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(1) It should be noted that long-term utilization of current chip surpluses by expanded pulp capacity would likely create new energy demands for mill residuals as fuel for power boilers.

Energy use in pulp mill power boilers now constitutes a significant demand for mill residuals in some regions. Moreover, economic analysis has shown that this use could potentially double. Increased use of hog fuel would in most mills require installation of a new power boiler with attendant high capital costs; again, the chief determinant of increased use is the price of natural gas.

Cogeneration of electricity at pulp mills is also a potential use for wood energy. These uses are currently constrained by the price structure for electricity established by B.C. Hydro and Power Authority.

(ii) Other Applications

Thermal electric power generation and liquid fuels production represent potential uses for mill residuals outside the forest industry. Feasibility studies of thermal electric power generation have been conducted for a 50 MW generation facility in Quesnel (B.C. Hydro, 1980). Though the project was found to be technically viable, the estimated cost of power generated was found unfavourable compared to other alternative power sources available. There was also the question of long-term security of supply (B.C. Hydro, 1982).

Liquid fuels production as a potential use for mill residuals is the focus of this study. The viability of this option is sensitive to the volume of mill residuals available (and hence of plant scale), the cost of acquiring mill residuals and the cost of alternative feedstocks.

(c) Cost Considerations

The supply and demand factors identified above will ultimately influence the volumes and costs of mill residuals in particular locations. There are two distinct types of cost associated with mill residual supplies:[1]

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(1) Transactions costs are ignored.

- costs of preparation and transport;
- opportunity costs to producers.

Mill residuals of various sizes and dryness are normally "hogged" or crushed to a consistent size and mixed before burning as waste. These costs are incurred as a normal operating cost of lumber production. In preparing mill residuals for sale rather than burning, additional costs may be incurred in storage bins or stockpiles, and in handling. These costs would vary among operations and, where waste burning is eliminated, would be offset by savings in burner operation.

Transportation costs are a critical element in the overall cost of mill residuals supply. Because of the low value to weight ratio, transportation costs circumscribe the size of the supply area, and hence the total volume of mill residuals available to an alcohol plant at a given location.

A second category is the opportunity cost of mill residuals to producers. The opportunity cost is defined in terms of the value of alternative uses or other opportunities foregone by a particular use of mill residuals. In potential energy applications, the value of mill residuals to producers depends upon the cost of replaced energy sources and the costs of conversion. The costs of conversion include considerations not only of capital costs to the firm, but also of alternative investment opportunities.

Finally, the cost of obtaining mill residuals for an alcohol plant may also be influenced by the ability of producers to demand a price reflecting a share of the value of mill residuals in alternative applications; that is, to obtain a share of the rents. This question depends upon the relative market power of producers in a hypothetical marketplace and cannot be quantified here. For the purposes of this analysis, the division of rents is not considered in the cost of mill residuals supply. Thus, we do not provide estimates of actual prices of wood waste feedstock, but the costs which must be compensated in order to command hog fuel supplies.

3.3 Mill Residuals Production, Utilization and Surplus: Williams Lake, B.C.

(a) Overview

Contained in this section are estimates of mill residue supplies, demands, available volumes, and delivered cost estimates for the Williams Lake area. Consideration is also given to supplementary supplies potentially available from Quesnel, some 120 km north of Williams Lake.

There are five major forestry firms operating in Williams Lake.[1] All five producers manufacture dimension lumber and each relies on natural gas as fuel for their lumber kilns. One firm, Weldwood, also operates a plywood and veneer plant, which utilizes sawdust and shavings in its veneer kilns. This energy use is the extent of existing demand for mill residuals within Williams Lake, since no pulp mills are located in the vicinity. Each firm currently operates on-site silo burners to dispose of mill residuals (including bark, sawdust and screen fines, shavings, solid wood waste and yard debris). In order to deal with environmental concerns associated with burner operations, the five producers have formed an ad hoc burner committee. Part of the work of this committee involved conducting an analysis of current mill residual volumes produced, and future surplus volumes under various scenarios of improved utilization. Their analysis is the basis for volume estimates provided in this report.

(b) Mill Residuals Supply

An assessment of current and potential mill residuals supply for the Williams Lake study area requires an examination of the regional timber supply situation and recovery standards of area processing facilities. Then estimates are provided of mill residual volumes available in and around Williams Lake.

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(1) These include Jacobson Bros. Forest Products Ltd., Weldwood of Canada Ltd. (Merrill and Wagner Operations), Pinette and Therrien Mills Ltd., Lignum Ltd., and West Fraser Forest Products Ltd.

(i) Timber Supply

There are two sources of timber available to mills in the Williams Lake area, Crown and private. Crown timber is the predominant source for Williams Lake producers, and indeed for all producers in the Cariboo Forest Region. The volume of timber billed by land status is shown in Table 3-2 for the Cariboo Forest Region. There are no Old Temporary Tenures in the Cariboo Forest Region, consequently timber resources management is largely the responsibility of the province, except for minor private holdings.

The allocation and management of Crown timber has recently been intensified with the establishment of Timber Supply Areas (TSA's) within each forest region. These TSA's are generally larger than formerly designated Public Sustained Yield Units (PSYU's) and have been designated for inventory management, administration and planning purposes. The TSA's are designated to reflect existing patterns of wood movement from harvesting sites to manufacturing plants. There are three TSA's in the Cariboo Forest Region corresponding to the three timber processing centers of Williams Lake, Quesnel and 100 Mile House.

Yield analysis reports have recently been completed for each Timber Supply Area by the B.C. Ministry of Forests. Contained in these reports is an assessment of the short-term (20 year) and long-term (250 year) timber production capability of each TSA. On the basis of these long-term supply considerations, existing forest resource demands and other public policy objectives, the timber supply of most TSA's have been recently reallocated. This reallocation of Crown timber to forestry firms is referred to as "apportionment" and replaces former annual allowable cut commitments known as "quota" and "third band" positions to forestry firms (B.C. Ministry of Forests, 1982a).

There are several categories of new timber apportionment. Forest Licenses predominate and are intended to represent a secure, long-term commitment by the Crown to forestry firms for an annual supply of timber. Forest License apportionments are shown in Table 3-3 for the forestry firms in Williams Lake.

TABLE 3-2

TOTAL VOLUMES OF ALL PRODUCTS, BILLED BY LAND STATUS CARIBOO FOREST REGION, 1979, 1980

(m^3)

Land Status	1979	1980
Tree Farm Licenses (TFL)	151,870	105,834
Timber Sale Harvesting Licenses (TSHL)	2,812,273	2,918,784
Timber Sale Licenses (TSL)	3,147,034	3,323,330
Farm Woodlot Licenses	312	4,399
Licenses to Cut	173,752	172,016
Right-of-Way	4,872	6,001
Miscellaneous	----	53,124
Total, Crown Lands	6,290,113	6,583,488
Crown Grant Lands	568,516	512,119
Dominion Reserves	----	----
Indian Reserves	14,383	20,302
Total, Private and Federal	582,899	532,421
(percent of total volume)	(8.4%)	(7.5%)
Total Volume, Billed All Lands	6,873,012	7,115,909

SOURCE: B.C. Ministry of Forests (1980a, 1979a).

It should be noted that this Annual Allotment does not include private timber supplies and may not reflect total volumes of Crown timber processed by particular firms in particular years. There may be some inflow of timber to a firm's timber operations from other timber supply areas. In addition, a firm may harvest within 50 percent of apportionment in any given year; it must, however, harvest within 10 percent of apportionment over a five-year period.

The following information has emerged from the Yield Analysis Report, B.C. Ministry of Forests, 1982c) for the Williams Lake TSA:

- the predicted harvestable Crown timber volume over the short term (20 years) amounts to 38,878,000 m^3, or an average of 1,944,000 m^3 per annum, after accounting for management constraints;

- the long run sustainable yield was determined to be about 2,550,000 m^3 per annum;

- the total Crown timber harvest commitment (AAC) over the short term (20 years) prior to the recent apportionments was 53,592,000 m^3, or 2,680,000 m^3 per annum;

- a rate of harvest of 2,972,000 m^3 per annum can be maintained for approximately 140 years. This rate is 17 percent above the long-run sustainable yield. This rate of timber harvest is required to ensure removal of present mature and over-mature timber stands to allow for maximum new forest growth;

- over the short term, the species distribution of timber demanded by mills cannot be maintained.

Interviews were conducted with Forest Service and industry personnel in Williams Lake to determine the extent to which changes are expected in the level and composition of Crown timber harvest over the next 20 years. These sources indicated that the contribution of private timber to total

TABLE 3-3

CROWN TIMBER APPORTIONMENTS, BY FIRM, WILLIAMS LAKE TIMBER SUPPLY AREA

m^3 per annum

Firm	Commitment Prior to April, 1982 "Quota"(1)	"Third Band"(2)	Total AAC	Current Commitment Forest Licence Apportionment (3)
Jacobson Bros.	306,070	236,250	542,320	538,230
Weldwood	425,440	173,460	598,900	531,160
Pinnette & Therrien	237,600	294,870	532,470	476,750
Lignum Forest Prod.	201,440	305,010	506,450	348,860
West Fraser	128,840	98,700	227,540	202,580
Starline Cedar (at Lac La Hache)	---	170,000	170,000	140,920
TOTAL			2,577,680	2,238,500
SUMMARY				
Commitment Prior to Apportionment				2,577,680
Forest License Apportionment				2,238,500
Other Apportionments(4)				261,500
Total Approved Annual Allowable Cut				2,500,000

SOURCE: B.C. Ministry of Forests, (1982b, 1982c).

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(1) Quota: timber commitment under TSHL's and certain TSL's.

(2) Third Band: volume of timber allocated above quota and close utilization. Third Band was an allotment for small timber which became merchantable with improvements in small log milling technology.

(3) Forest License apportionments came into effect in the Williams Lake Timber Supply area in April, 1982 and represent the perpetual commitments of specific timber volumes to licensed firms, subject to minor fine-tuning.

(4) Other apportionments include Timber Sale Licenses to designated applicants and under the Small Business Enterprise Program, Woodlot Licenses, and an apportionment as Forest Service Reserve.

harvest volumes, in the Cariboo Forest Region, will decline somewhat, but the extent of this decline is not known. As noted in the Yield Analysis Reports, the species composition of timber harvest will also change, but this change is not expected to affect mill residuals production markedly.

(ii) Recovery Factors

The relationship between aggregate timber supply and the volume of mill residuals produced depends upon milling efficiencies in processing of log inputs into marketable forest products. There are two recovery factors applicable to a typical sawmilling operation, the lumber recovery factor (LRF) and the chip recovery factor (CRF). The production of mill residuals is related less to lumber recovery than to chip recovery. This is so because improvements in lumber recovery are more likely to occur at the expense of residuals production. For example, in Williams Lake, Pinnette and Therrien recently installed a finger-joining plant to produce dimension study lumber from short stud ends. Previously the short stud ends were chippable material.

The average percentages of solid wood recovered from standing timber for the Cariboo Forest Region are contained in Table 3-4. It should be noted that these percentages exclude bark and sound wood. On average, 89 percent of timber volumes (solid wood equivalent) is recovered as sawlogs. Of the sawlog volume, 36 percent is recovered as lumber, 36 percent as chips and the remainder as residuals and waste. For the purpose of this study, it can be assumed that these relationships will hold constant over the forecast period.

(iii) Mill Residuals Production

Estimates of current volume of mill residuals produced in Williams Lake are shown below in Table 3-5. It should be noted that the estimates of the burner committee have been converted from thousand cubic feet (mcf) solid wood equivalent (SWE) to gravity packed units (GPU's) and to oven dried tons (ODt's). Gravity packed units are the common marketing unit for hog fuel in

TABLE 3-4

AVERAGE PERCENTAGES CONVERSION FACTORS FOR TIMBER, CARIBOO FOREST REGION

Material	Percent Solid Wood[1]
Standing Timber	
- pulp logs	6 %
- avoidable residues	2
- unavoidable residues	3
- recovered sawlogs	89
Total	100 %
Sawlogs	
- lumber	36 %
- chips	36
- sawdust	11
- shavings	11
- losses	6
Total	100 %

SOURCE: Reid, Collins and Associates (1978), Appendix V.

(1) Percentages based on solid wood only; bark and unsound wood volumes are excluded.

TABLE 3-5

MILL RESIDUALS PRODUCTION, WILLIAMS LAKE

Material	I Total Residual Quantities by Type (mcf/year SWE)	II Conversion SWE to GPU(1) (GPU/mcf)	III Derived Residual Quantities (3) (GPU)	IV Derived Residual Quantities (4) (ODt)
Bark	12,118	13.70	166,000	166,000
Yard Debris	1,994	15.15	30,000	30,000
Solid Wood	11,949	15.15(2)	181,000	181,000
Sawdust	8,113	13.89	113,000	113,000
Screen Fines	1,986	13.16	26,000	26,000
Shavings	7,308	22.22	162,000	162,000
TOTAL	43,468	---	678,000	678,000

SOURCES: Col. I - Williams Lake Burner Committee, Estimates, Revised, May 1981.
II - Reid, Collins & Associates (1978), Table 8.

(1) One GPU (Gravity Packed Unit) contains 200 cu.ft. of material compacted by gravity only.

(2) Assumes solid wood converted at the same ratio as yard debris.

(3) Col. I times Col. II; figures rounded to thousands.

(4) One GPU is assumed to be equivalent to one ODt.
According to Forintek Canada Corp. (1979), estimates of m^3 SWE per ODt for residues vary by species from 1.96 to 3.33 m^3 (SWE)/OD tonne. According to the species distribution of timber in the Cariboo Forest Region, an average weighted factor of 2.3665 m^3/(SWE)/OD tonne, or 83.5729 $ft.^3$ (SWE)/OD tonne would apply as an average residue conversion factor. Using this conversion factor to the total residual volume in Col. I would indicate total residual weight of 520,000 ODt's, which is roughly 77 percent of the number of GPU's. However, as noted earlier volume to weight conversions depend importantly on the residuals components considered, which this latter conversion ignores. See P. 3-19 for further discussion of conversion factors.

the British Columbia Interior, a measure of volume representing 200 cubic feet of material compacted by gravity only. Obviously the solid wood equivalent volume in a GPU will vary as the residuals components change. The conversion of mill residuals volumes from solid wood equivalent to GPU's is shown in Columns II and III of the table. For energy analysis, residue volumes are best expressed in metric oven dried tonnes, a measure of weight consisting of 1000 kg of dry material. The conversion from a volume measure (GPU's) to a weight measure is not straightforward, since variations in species and water content affect the relationship. According to Forest Engineering Research Institute of Canada (FERIC) researchers, one GPU can be expected to weigh roughly 2,000 kg and contain 50 to 60 percent water (pers. comm.). On that basis, a GPU would contain approximately the equivalent of 1,000 kg of dry wood, although the precise dry wood content of a given GPU could vary substantially. For simplicity this report assumes that one GPU is equal to one ODt, as adopted in McDaniels Research (1981).

(c) Alternative Demands for Mill Residuals

(i) Existing and Potential Demands

The existing demand for mill residuals in Williams Lake consists of a relatively minor volume of shavings used to fuel Weldwood's Merrill and Wagner operation veneer kiln. As shown in Table 3-6, all sawmills currently rely on natural gas as fuel for their lumber dryers. Aside from the 74,000 ODt used by Weldwood, all [illegible] residues from Williams Lake operations are wasted.

The most direct potential use of these residues for energy purposes would be to replace natural gas in the drying kilns of the five Williams Lake mills. The economics of converting existing natural gas kilns to hog fuel have recently been examined in a study for Inland Natural Gas Co. Ltd. (B.H. Levelton & Associates, 1981). A summary of this report is contained in Appendix B. Briefly, four types of wood burning equipment were assessed as potential replacements for existing natural gas fuel systems. The economics of conversion to wood waste are heavily influenced by future gas prices. Based on a range of gas price forecasts most of the systems studied were found to be potentially economically attractive to mill owners.

TABLE 3-6

CURRENT MILL RESIDUALS UTILIZATION
WILLIAMS LAKE

Facility	Rated Capacity(1) ('000 board ft./shift)	Kiln Type	Vol. Hog Fuel Used (ODt)
Sawmills			
Jacobson Bros.	225	Natural gas	---
Weldwood	170	Natural gas	---
Pinnette & Therrien	400	Natural gas	---
Lignum Forest Prod.	225	Natural gas	---
West Fraser	135	Natural gas	---
Plywood Plants	(million sq.ft./year)		
Weldwood	120	Wood waste	74,000
TOTAL			74,000

SOURCES: Madison's (1980), B.C. Ministry of Industry and Small Business Development (1980).

(1) Where annual capacity figures are used, daily capacities have been derived on the basis of 440 shifts per year.

Despite the apparent economic attractiveness, investment in wood waste energy systems has not yet occurred in the Williams Lake sawmilling industry; apparently other investment projects have taken priority. One factor may be that the private costs of waste disposal are only marginally reduced by the installation of wood-burning fuel systems and thus do not greatly add to the private benefits of conversion. The wood fuel requirements of sawmills are typically only about one-tenth of mill residual production (B.H. Levelton & Associates, 1981) and as a result, waste disposal operations are still necessary. If waste disposal costs were completely eliminated by the operation of a hog fuel energy system, there would be a considerably greater economic impetus for conversion.

Nevertheless, it does seem reasonable to expect that the five mills could eventually supplant their natural gas requirements through the use of wood energy systems. Although the relative values of wastes in this application have not been modelled in detail, it can be assumed that the volumes required by Williams Lake lumber kilns would not be available for alcohol production.

Another potential energy use would be in regional pulp mills for process heat or cogeneration. The nearest pulp mill, Cariboo Pulp and Paper in Quesnel, is surrounded by huge amounts of available wood waste, and in fact has its own waste disposal problem. This situation is typical of other mills which are more distant from Williams Lake. Therefore, no alternative use is foreseen for pulp sector energy requirements.

The final potential energy use would be as fuel for a wood energy thermal electric plant. Although a plant of this type has been analyzed in detail for Quesnel, B.C. Hydro has apparently no plans to proceed with it. At least from the utility's viewpoint, the plant is uneconomic compared to other generation alternatives. In that case, the (private) opportunity cost of mill residuals in electrical generation can be assumed to be zero.

The chief potential demand for mill residuals from Williams Lake as fibre would occur from the pulp-milling sector. For this use to be realized, new pulp capacity would have to be constructed in the region, and all available chip supplies (which are a more attractive pulp furnish) would have to be utilized. Forest Service and industry personnel do not consider Williams Lake as a suitable location for added pulp milling capacity, primarily due to water supply limitations. However, there is the potential for expanded pulp mill capacity at Cariboo Pulp and Paper in Quesnel. The installation of a sawdust digestor line has been considered by Cariboo Pulp and Paper, but no plans are under active consideration at this time. Thus increased utilization of sawdust, shavings, and other "chippable" mill residuals from Williams Lake is dependent on added expansion of pulp capacity elsewhere in the region, or on export opportunities.

(ii) Future Demand Scenarios

In order to account for uncertainties over alternative uses, three scenarios of wood waste utilization (and availability) have been developed. These scenarios have been adapted from data in a report prepared for the ad hoc Williams Lake burner committee by Magnus Engineering Ltd. (1981), and is the starting point for all three scenarios with current 1981 production of mill wastes. According to a representative of the burner committee, the 1981 level of residue output can be assumed typical of full capacity production, and can be further assumed to continue over the forecast period. Thus it is implicitly assumed that the level of cut and industry recovery factors will remain constant, which is consistent with earlier discussion in this chapter. The scenarios differ on the extent of alternative uses assumed for Williams Lake residues; they include:

Scenario I: Assumes all Williams Lake mills use wood waste to fuel lumber kilns.

Scenario II: Assumes Scenario I, and all Williams Lake mills maximizing the recovery of chippable material from yard debris and solid wood residuals, for use by regional pulp mills, or for export.

Scenario III: Assumes Scenario II, and all Williams Lake mills maximizing the recovery of sawdust, shavings and screen fines as supplementary pulp furnish.

The volumes of surplus mill residuals available under each scenario are shown in Table 3-7. In all scenarios, bark is assumed as the residuals component used for the mills' kiln heat.[1] By assuming that bark only is used for process heat, the scenario conservatively estimates the total volumes of surplus mill residuals. In all cases, data on mill energy requirements and composition of residue flows have been supplied by the Williams Lake burner committee.

By adopting this "scenario" approach to estimating wood waste volumes available for alcohol feedstock, we skirt the issue of estimating opportunity costs. This limitation to the analysis was necessary because neither the data nor the resources required for modelling the willingness of alternative users to pay for Williams Lake wood waste was at hand. Because the quantities available for alcohol production are calculated as a residual, each scenario implicitly assumes that the identified uses preclude (that is, could outbid) an alcohol plant for supplies.

The question arises as to which scenario is appropriate for the cost analysis. Scenario I involves an alternative use that appears currently economically feasible; it thus represents the probable short-term outlook. Scenario II is more remote, and would require a rise in chip prices to make this increased fibre recovery economically viable. This scenario can be viewed as the probable (or possible) long-term outlook. The third scenario is the absolute minimum that could be available for alcohol conversion. These scenarios are summarized in Table 3-8.

(d) Regional Mill Residuals Production and Utilization

Aside from the material at Williams Lake, marginal supplies of mill residuals are also potentially available from the other producing centers in the Cariboo Forest Regions, which include 100 Mile House and Quesnel. Tables

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(1) Though bark has a higher energy value per unit than other residuals components, it also has a higher water content. Wood-fired combustion systems to accommodate wet fuel are typically more expensive than wood-fired systems using drier mill residual materials such as shavings and sawdust (see Levelton, 1981 in Appendix). In choosing a wood energy system, operators would weight the potential cost savings of using drier material over bark against the current and potential value of this wood fibre in alternative applications.

TABLE 3-7

MILL RESIDUALS UTILIZATION SCENARIOS
WILLIAMS LAKE

(ODt's)

	Scenario		
Mill Residuals Dispostion	I	II	III
Total Production(1)	678,000	678,000	678,000
Process Heat(2)	112,000	112,000	112,000
Recovery of Chippable Material from Debris (3)	---	194,000	194,000
Recovery of all Wood Fibre(4)	---	---	266,000
Surplus Mill Residuals(5)	566,000	372,000	106,000

SOURCE: Magnus Engineering Ltd. (1981). All data have been converted from mcf/year SWE to ODt's as shown in Table 3-5.

(1) All data have been converted from mcf/year SWE to ODt's as shown in Table 3-5.

(2) Assumes all mills using bark for fuel; total = 8,199 mcf/year (SWE) x 13.7 GPU/mcf (SWE) = 112,000 GPU.

(3) Indicated recovery of chips = 44 percent yard debris, 100 percent of solid wood: .44(1994) + 11,949 mcf/year (SWE) x 15.15 GPU/mcf (SWE) = 194,000 GPU.

(4) Because of the heterogenity of this material, the figure here is determined as a residual in the derivation; ie: 678,000 - 112,000 - 194,000 - 106,000 = 266,000.

(5) Indicated remaining bark residue = 7,748 mcf/year (SWE) x 13.7 GPU/mcf = 106,000 GPU.

TABLE 3-8

SUMMARY OF SCENARIOS FOR CURRENT AND FUTURE WILLIAMS LAKE MILL RESIDUAL AVAILABILITY

Scenario	Description	Implicit Assumptions	Volume (ODt's)
I	Probable Short Term	Current market conditions continue, with conversion to wood fuel in existing kilns, but no increased recovery of residuals for fibre use.	550,000
II	Probable Long Term	Increased demand for supplementary fibre supplies in pulp industry, or for export. Substantial increases in chip prices, due to complete utilization of conventional chip supplies.	350,000
III	Minimum	Utilization of virtually all fibre, with only surplus bark available.	100,000

TABLE 3-9

CROWN TIMBER APPORTIONMENTS BY FIRM, QUESNEL TIMBER SUPPLY AREA (1)

(m^3 per annum)

	Commitment Prior to April, 1982			Current Commitment
Firm	"Quota"	"Third Band"	Total	Forest License Apportionment
West Fraser	346,670	409,140	755,310	---
Weldwood	278,890	238,980	517,870	468,650
Brownmiller	---	---	---	339,450
Ernst	10,610	323,560	334,170	302,410
Slocan	52,300	230,920	283,220	256,300
Weier	---	158,590	158,590	143,510
Patchett & West Fraser	---	---	---	125,580
Patchett	---	---	---	112,210
Patchett, Brownmiller & West Fraser	---	---	---	106,740
Clear Lake Sawmills	---	56,640	56,640	51,260
Totals			2,106,300	1,906,110

SUMMARY

Commitment Prior to Apportionment	2,106,300
Forest License Apportionment	1,906,110
Other Apportionments	393,890
Total Approved Annual Allowable Cut	2,300,000

SOURCE: B.C. Ministry of Forests (1982b, 1980c).

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(1) See notes to Table 3-3 for explanation.

TABLE 3-10

CROWM TIMBER APPORTIONMENTS BY FIRM, 100 MILE HOUSE TIMBER SUPPLY AREA (1)

(m^3 per annum)

	Commitment Prior to April, 1982			Current Commitment
Firm	"Quota"	"Third Band"	Total	Forest License Apportionment
Ainsworth Lumber Co.	364,000	129,080	493,080	512,360
Weldwood, Camin Lake	382,430	93,090	475,520	441,470
Lignum Forest Products	---	---	---	108,890
Evans Products Co.	106,030	---	106,030	62,280
Total			1,074,630	1,125,000

SUMMARY	
Commitment Prior to Apportionment	1,074,630
Forest License Apportionment	1,125,000
Other Apportionments	125,000
Total Approved Annual Allowable Cut	1,250,000

SOURCE: B.C. Ministry of Forests (1982b, 1981a).

(1) See notes to Table 3 for explanation.

3-9 and 3-10 show the volume of available Crown timber in both regions.

100 Mile House

The 100 Mile House TSA Yield Analysis Report (1981a) indicates that the timber supply commitment (prior to apportionment) of 1,074,630 m^3 per year can be maintained over the next 20 years. The species distribution of timber supply also compares favourably with existing demand. The 100 Mile House TSA is slightly greater than half the approved AAC for Quesnel and precisely half that of Williams Lake. Similar to the other TSA's in the Cariboo Forest Region, private timber augments supply at 100 Mile House. Processing centers include 100 Mile House, Chasm and Clinton. Without specific information on mill residuals production and utilization in this TSA, the level of harvest indicates that mill residuals production would be considerably less than in Williams Lake or Quesnel. Also mill residuals are currently utilized for process heat by Ainsworth Lumber Company in both Chasm and 100 Mile House.

Quesnel

The Quesnel TSA Yield Analysis Report (1980c) indicates that, over the short term (20 years), existing timber commitments can be accommodated in the management unit. The total timber volume considered to be available for harvesting at Quesnel (that is, "available for harvesting schedule"), over the next 20 years equals 66,952,000 m^3 or 3,347,600 m^3 per year. The actual available volume in any year may be less, depending upon specific management constraints. In addition, the species distribution of existing mill demand will change somewhat, although the change is not expected to have an appreciable effect on mill residuals production.

Although Quesnel is further than 100 Mile House from Williams Lake, transportation logistics favour Quesnel as a marginal supply source. The current flow of chips produced in Williams Lake is predominantly (80 percent) northward to pulp mills in Quesnel and Prince George. Mill residuals could therefore be transported from Quesnel to Williams Lake in the otherwise empty truck backhaul.

There is considerable information on mill residuals production and utilization in Quesnel as a result of feasibility studies conducted by B.C. Hydro into the development of a 50 MW wood fueled thermal electricity facility at Quesnel (B.C. Hydro, 1979 and 1980). An individual survey was conducted of all mills in Quesnel to determine current and future mill residuals production utilization. The results of this survey are shown in Table 3-11.

In the B.C. Hydro studies, the current surplus of 385,000 ODt is predicted to decline to 267,000 ODt by 1990 due primarily to increased utilization. For our purposes, the B.C. Hydro estimate of 267,000 ODt per year can be taken to represent the long-term waste supply available from Quesnel which could be utilized as supplementary feedstock at Williams Lake.

(e) Mill Residuals Costs

(i) Costs of Preparation

Mill residue preparation involves costs for "hogging", or crushing various components to a consistent size for burning. When hog fuel is sold, payment is typically made to the supplier to cover this preparation cost.[1] However, this cost still is incurred when hog fuel is not marketed, because hogging costs are a normal part of disposal costs for mills with waste burners. For our purposes, preparation costs can be estimated subsequently as a component of disposal costs avoided by energy use.

(ii) Costs of Transportation

Transportation is typically the largest component of costs in acquiring mill residuals for energy. Because the mills in Williams Lake operate on-site burners, there are no available data regarding actual hauling costs in the area. However, the same trucks used to haul chips can be used to haul prepared mill residuals, so the costs are likely comparable. The costs of hauling mill residuals from producers in Williams Lake to a nearby alcohol plant can be inferred from costs incurred by Cariboo Pulp and

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(1) This does not occur in Williams Lake as no mill residuals are marketed.

TABLE 3-11

TOTAL CURRENT (1980) MILL RESIDUALS PRODUCTION, UTILIZATION AND SURPLUS, QUESNEL

Total Residuals Quantities by Firm	Production (GPU/ODt)	Utilization (GPU/ODt)	Surplus (GPU/ODt)
Two-Mile Flat			
Quesnel Forest Products	73,000	---	73,000
Weldwood (Planer Mill)	30,000	---	30,000
Weiers Sawmill	52,000	---	52,000
West Fraser	120,000	---	120,000
Ernst Forest Products	88,000	---	88,000
South Quesnel			
Weldwood (Sawmill & Plywood)	195,000	81,500	113,500
Cariboo Pulp & Paper(1)	10,000	160,000	150,000
Strathnaver			
Dunkley Lumber	59,000		59,000
TOTAL	627,000	241,500	385,500

SOURCE: B.C. Hydro (1980), Appendices 1 and 5.

(1) Residuals production of chip fines.

Paper in hauling mill residuals from producers in the Two-Mile Flat area of Quesnel to its pulp mill. The hauling costs are largely fixed over this short haul (approximately 8 km return) and primarily reflect loading and unloading time. A similar situation would likely exist for hauling mill residuals from Williams Lake producers to a nearby alcohol plant. Costs of transporting mill residuals from Quesnel to Williams Lake are based on existing costs for transporting chips from Williams Lake to Quesnel, and are shown in Table 3-12. More detailed information on the calculation of transportation costs is provided in Appendix C.

It should be noted that these estimates are conservative; that is, they likely err on the high side. For an alcohol plant located in one of the two timber milling areas of Williams Lake (Glendale or South West area), a conveyor system may be more economical than trucking for some or all the mill residuals volumes. Moreover, the costs of transporting mill residuals from Quesnel are based on current costs of transporting chips from Williams Lake with an empty backhaul. With the elimination of an empty backhaul, the average costs of transporting chips and mill residuals would, theoretically, be lower. However, it is uncertain how such cost savings would be apportioned, so no account is taken of these savings in this analysis.

(iii) Opportunity Costs

The opportunity cost of mill residuals to producers is measured by the benefits or revenues given up in the best alternative use for the resource. In this analysis, no current use is displaced for the volumes of mill residuals considered.

Another component of the opportunity cost lies in the perceived future value, or option value, for mill residuals. In B.C. Hydro's analysis of a thermal electric project in Quesnel, it was suggested that mill operators desire to maintain their future options regarding potential uses for mill residuals. This was reflected in the unwillingness of producers to make

TABLE 3-12

MILL RESIDUALS TRANSPORTATION COSTS
WILLIAMS LAKE (1)

Supplies From	
Williams Lake	$ 4.00/ODt
Quesnel	14.00/ODt

(1) See Appendix C for detailed calculation.

long-term supply commitments to B.C. Hydro at a nominal price (B.C. Hydro, 1982). In the present study, the issue of option value is addressed by accounting, to the extent possible, for increased utilization of mill residuals by the forest industry, and excluding that volume from the surplus available for alcohol production. The options for future use of mill residuals discussed here can be assumed to be valued at zero.

(iv) Avoided Disposal Costs

Costs now incurred by mill operators for disposal of wood wastes may ultimately comprise an effective "credit" against the cost of residue supplied to an alcohol plant, since the disposal costs could potentially be avoided. Disposal costs in Williams Lake include two components: crushing and mixing residues, and the capital and operating costs associated with on-site burners. Since all firms in Williams Lake operate on-site burners, there are no transportation costs incurred for disposal. These disposal costs are largely fixed and do not vary greatly with modest changes in volumes burned. That is, marginal disposal costs are typically well below average costs (Williams Lake burner committee, pers. comm.).

We noted earlier that interviews suggest that disposal cost savings have not provided a significant economic impetus for producers to utilize wood waste in kiln dryers. This is typically the case because only a small percentage of a given mill's residue stream would likely be required to fuel its kiln dryers, with large volumes of residuals remaining for disposal. The low marginal cost savings do not provide much assistance in justifying a wood fueled drying kiln.

On the other hand, a given mill's disposal costs would be eliminated if the total volume of its residues is directed to an alternate use. In Williams Lake, disposal costs are estimated to average roughly \$3.00/ODt.[1] Some or all of this average cost would represent a potential credit in the supply of mill residuals for alcohol production, if a mill's disposal requirements are significantly reduced or eliminated by sale of its residues.

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(1) Preliminary estimate, Williams Lake burner committee (pers. comm.).

In estimating the costs of wood waste supplies, avoided disposal costs have not been explicitly shown as a credit against other cost in this analysis. This approach was adopted because of the uncertainties regarding supply commitments, and the volumes that could be obtained from each sawmill. If marketing arrangements call for only a partial volume from a given supplier, the marginal costs of disposal might decrease, but the larger fixed costs of disposal remain, and major savings would not be realized. To the extent that cost savings in waste disposal would actually occur, this study overestimates the actual costs of wood waste supplies for an alcohol facility in Williams Lake.[1]

(v) Long-Term Considerations

Over the economic life of an alcohol plant, it is assumed that no change will occur in real terms for either transportation costs or opportunity costs. This assumption is based on the view that transportation costs incorporate such a broad spectrum of inputs that they are unlikely to increase faster than the general price level.

(f) Williams Lake: Mill Residuals Supply Curve

Mill residuals volume and cost estimates for Williams Lake can be conveniently summarized by means of a supply curve shown in Figure 3-1. It should be noted that this supply schedule differs from conventional supply curves in two respects. First, the schedule represents the volumes available at a given cost rather than the volumes available at a certain price. Second, the supply curve is "kinked", reflecting the availability of all mill residuals in Williams Lake at one cost, and supplementary supplies from Quesnel at a uniform higher cost.

The figure represents the long-term situation, based on volumes estimated under Scenario II for Williams Lake (see Table 3-7), with long-term supple-

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(1) Obviously, this issue would require further investigation before any commitments are made with suppliers regarding prices and volumes for mill residues.

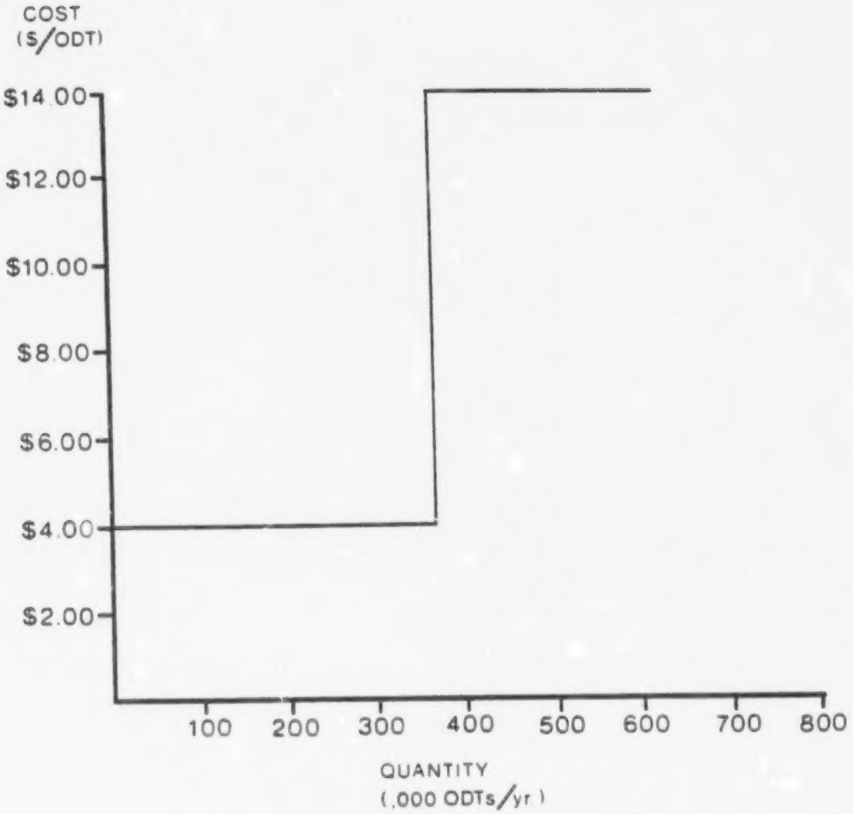

FIGURE 3-1

MILL RESIDUALS SUPPLY SCHEDULE FOR WILLIAMS LAKE mentary volumes available. It should be noted that if the full average costs of waste disposal were allowed as a credit against supply costs to an alcohol plant, the portion of the curve depicting Williams Lake supplies (that is, from 0 to 350,000 ODt per year) would shift downward to $1 per ODt at all volumes.

3.4 Mill Residuals Production, Utilization and Surplus: Kamloops Area

(a) Overview

Kamloops is the second study area chosen for analysis of mill residuals supplies. Unlike Williams Lake, wood wastes in the Kamloops vicinity are dispersed over a number of regional centers; the volumes and cost of residuals in the area are thus highly influenced by transportation costs. The Kamloops region also differs from Williams Lake in the extent of existing utilization of mill residuals. In Kamloops, the Weyerhaeuser Canada Ltd. pulp mill is a significant user of mill residuals, including sawdust as pulp furnish and mixed residuals as fuel for the pulp mill power boilers. Weyerhaeuser is the only purchaser of mill residuals in the Kamloops area. In addition a number of producers use their own residues for energy in lumber and veneer drying kilns.

For the purposes of this analysis, the Kamloops wood waste supply region is delineated as the area within a 200 km road haul. This is an arbitrary boundary; the actual supply area would be defined on the basis of the amount an alcohol plant could afford to pay to transport wood wastes, which is in turn a function of the revenues and costs associated with the facility. It is expected that the assumed supply area would tend to underestimate rather than overestimate economically attractive supplies.

(b) Mill Residuals Supply

(i) Timber Supply

Crown land is the predominant source of timber supply to forestry operations in the Kamloops Forest Region. Private timber suppliers do not comprise a large percentage of total timber volumes, although they are not inconsequential (see Table 3-13). The percentage is expected to steadily decline as private timber supplies are liquidated in the region (B.C. Ministry of Forests, pers. comm.).

Kamloops Forest Region Crown timber is managed within four Timber Supply Areas: Kamloops, Lillooet, Merritt and Okanagan. Yield Analysis Reports have been completed for each TSA. The short-term (20 year) and long-term timber supply analyses are summarized below: (1)

Kamloops (May, 1981)

- there is a sufficient volume of mature timber available to supply the present commitment to licences for the next 20 years;
- the long-term sustainable yield was calculated to be 1,728,711 m^3 per year, approximately 75 percent of present commitment level.

Lillooet (December, 1980)

- there is enough operable, mature timber to supply the existing commitments to licensees for the next 76 years. However, when accessibility, cut and leave patterns, and species preference factors are considered in the short-term analysis, an available timber supply of only 15 years is indicated.
- the long-term sustainable yield was considered slightly in excess of existing commitment level to the industry.

Merritt (February, 1981)

- the present commitment level can be maintained for the next 50 years;
- the long-term sustainable yield is approximately 86 percent of present commitment.

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(1) B.C. Ministry of Forests (1981b, 1981c, 1980d, 1979b).

TABLE 3-13

TOTAL VOLUME OF ALL PRODUCTS BILLED, BY LAND STATUS KAMLOOPS FOREST REGION, 1979, 1980

Land Status	1979	1980
	(Volume m^3)	
Tree Farm Licenses	790,000	815,096
Timber Sale Harvesting Licenses	3,671,290	3,475,587
Timber Sale Licenses	3,254,634	3,716,854
Farm Woodlot Licenses	63	342
Licenses to Cut	98,980	41,985
Right of Way	5,114	361
Special Timber Licenses	280,540	154,786
Miscellaneous	7,442	84,268
Total Crown Land	8,108,718	8,289,279
Crown Grant Lands	609,560	477,728
Dominion Reserves	177	595
Indian Reserves	18,301	18,444
Total Private and Federal	628,038	496,767
(percent per total volume)	(7.2%)	(5.7%)
Total Volume Billed, All Lands	8,736,756	8,786,046

SOURCE: B.C. Ministry of Forests (1980a, 1979a).

Okanagan (November, 1979)

- the present species mix usage pattern cannot be maintained in the short term;
- the current imbalance in age class will result in a decline in harvest levels after 80 years.

A reallocation of timber cutting rights has recently been completed for forestry operations operating in the Kamloops Forest Region. This "apportionment" is intended to represent a long-term annual supply commitment of timber to forestry firms. As shown in Tables 3-14 and 3-15, the apportionment has resulted in a slight downward adjustment of annual timber volumes available in the Kamloops and Merritt TSA's. This adjustment reflects both the resource capabilities as determined in the yield analysis as well as the provincial government's desire to make more harvesting rights available to small forestry operators. Similar apportionments were made in the Lillooet and Okanagan TSA's.[1]

(ii) Regional Residue Production Estimates

Gross estimates of mill residuals production within Kamloops were made in the Reid, Collins (1978) study of hog fuel availability in British Columbia; these estimates were based on log consumption and applied conversion factors. Questionnaires were used by Reid, Collins to supplement information on conversion factors and to provide information on actual mill residuals usage. The conversion factors used by Reid, Collins for the Kamloops Forest Region are shown below in Table 3-16, and aggregate mill residuals production estimates are shown in Table 3-17.

Interviews with representatives of the Ministry of Forests and forestry industry firms indicated general agreement with Reid, Collins' approach and study results. Moreover, the interviewees indicated that there was no

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(1) For reasons noted earlier, the apportionments are not directly indicative of timber volumes consumed annually by mills. This apportionment does, however, indicate the longer-term trend in timber supply and consequently the long-term trend in production of mill residuals.

TABLE 3-14

CROWN TIMBER APPORTIONMENTS, BY FIRM, KAMLOOPS TIMBER SUPPLY AREA (1)

(m^3 per annum)

Firm	Commitment Prior to April, 1982			Current Commitment
	"Quota"	"Third Band"	Total AAC	Forest License Apportionment
Balco Industries (Fadear & Heffley)	451,200	286,270	737,470	674,830
Weyerhaeuser				
Kamloops	124,000	117,900	241,900	480,290
Vavenby	183,510	94,970	278,480	
Clearwater Timber	138,170	155,340	293,510	283,830
Holding Lumber Co.	184,120	106,430	290,550	262,730
Evans Products	207,470	28,320	235,810	157,850
G. Smith	9,600	62,500	72,100	65,200
Others				56,150
Total			2,309,870	1,980,880

SUMMARY

Commitment Prior to Apportionment	2,309,870
Forest Licence Apportionment	1,980,880
Other Apportionments	369,120
Total Approved Annual Allowable Cut	2,350,000

SOURCE: B.C. Ministry of Forests (1982b, 1981b).

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(1) See notes to Table 3-3 for explanation.

TABLE 3-15

CROWN TIMBER APPORTIONMENTS, BY FIRM, MERRITT TIMBER SUPPLY AREA (1)

(m^3 per annum)

	Commitment Prior to April, 1982			Current Commitment
Firm	"Quota"	"Third Band"	Total	Forest Licence Apportionment
Weyerhaeuser (Merritt & Princeton)	386,090	330,450	716,540	565,140
Balco, Nicola Div.	177,310	148,490	325,800	281,160
Aspen Planers (Similkameen, Nicola, Kamloops, Dewdney)	67,240	33,250	100,490	79,870
Other				21,430
Total			1,142,830	947,600

SUMMARY

Commitment Prior to Apportionment	1,142,830
Total Forest License Apportionments	947,600
New Forest Licenses	88,000
Other Apportionments	114,400
Total Approved Annual Allowable Cut	1,150,000

SOURCE: B.C. Ministry of Forests (1982b, 1981c).

(1) See notes to Table 3-3 for explanation.

TABLE 3-16

AVERAGE PERCENTAGES CONVERSION FACTORS FOR TIMBER KAMLOOPS FOREST REGION (1)

Material	Percent Solid Wood(2)
Standing Timber	
- pulp logs	5 %
- avoidable residues	3
- unavoidable residues	8
- recovered sawlogs	84
Total	100 %
Sawlogs	
- lumber	41 %
- chips	34
- sawdust	8
- shavings	11
- losses	6
Total	100 %

SOURCE: Reid, Collins & Associates (1978), Appendix V.

(1) Based on simple average for all PSYU's and TFL's.

(2) Percentages based on solid wood only; bark and unsound wood volumes are excluded.

TABLE 3-17

TOTAL HOG FUEL PRODUCTION, UTILIZATION AND SURPLUS KAMLOOPS AND SHUSWAP, 1976 (1)

(ODt's)

Region(2)	Mill Residuals Production	Utilization	Surplus
Kamloops	580,000	120,000	460,000
Shuswap	263,000	115,000	148,000

SOURCE: Reid, Collins & Associates (1978).

(1) Excludes surplus chips.

(2) Kamloops includes production centers of Kamloops, Savona, Merritt, Vavenby and Clearwater; Shuswap includes production centers of Revelstoke, Canoe, Chase, Malakwa, and Salmon Arm.

reason to expect any significant change in the overall production of wood wastes since the Reid, Collins report was completed. Consequently, it was decided to use the Reid, Collins estimates to indicate the gross quantities of wood wastes produced in the area. Of greater interest are the actual quantities and cost of materials potentially available for alcohol production; estimates of these parameters are derived subsequently.

The regions designated in the Reid, Collins (1978) study do not correspond with the more recent Timber Supply Area designation of B.C. Forest Service. Reid, Collins' Shuswap hog fuel region consists of Revelstoke, Canoe, Chase, Melakwa and Salmon Arm, while the Kamloops hog fuel region consists of Kamloops, Savona, Merritt, Vavenby and Clearwater. The TSA designation was made to reflect patterns of log movement from timber areas to production centers. Neither designation precisely corresponds to the 200 km economic zone assumed for the movement of mill residuals to a potential alcohol plant at Kamloops.

(c) Alternative Demands for Mill Residuals

The alternative demands for mill residuals in the Kamloops area include fibre and energy uses.

(i) Fibre Demand

Weyerhaeuser is the only purchaser of mill residuals in the Kamloops study area; its Kamloops pulp mill uses sawdust as one component of its pulp furnish, and mixed residuals are used as boiler fuel. Weyerhaeuser's demand for sawdust for pulping is estimated at approximately 250,000 GPU per annum (Weyerhaeuser, pers. comm.).[1]

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(1) All information regarding chip and wood waste volumes in the Kamloops area was originally provided in terms of bone dry units (or BDU's) by interviewees. A BDU is a measure of dry weight equal to 2,400 lbs. For simplicity, these units have been converted on the assumption that one GPU = one BDU, and then, in turn, that one BDU = one ODt.

The potential demand for mill residuals for fibre uses is closely related to the potential supply and demand for wood chips. At present, there is a surplus of chips throughout southeastern British Columbia, including the Kamloops and Nelson Forest Regions. This surplus over existing pulp mill demand is shown subsequently, in Table 3-18.

A study has recently been completed of fibre resources and the opportunities and constraints of expanded pulp milling capacity in southeastern British Columbia (B.C. Ministry of Forests, 1982). In this study, potential future demands were identified for chips and clean mill residuals (sawdust and shavings) resulting from expanded pulp capacity in the southeast. Expansion of pulp capacity was identified as follows:

East Kootenay Supply Area

- increased pulp capacity of 750 mtpd (metric tons per day), consisting of 500 mtpd chip pulp and 150 mtpd sawdust pulp.

West Kootenay Supply Area

- increased pulp capacity of 550 mtpd, consisting of 400 mtpd chip pulp and 150 mtpd sawdust pulp.

Kamloops Supply Area

- addition of 300-500 mtpd TMP (thermomechanical pulp[1]) or CMP (chemi-mechanical pulp[2]) capacity in the Kamloops area;
- addition of a 900 mtpd kraft pulp[3] mill in the Kamloops region with capacity for 750 mtpd chip pulp and 150 mtpd sawdust pulp.

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(1) The thermomechanical pulping process involves steaming chips before mechanically separating the fibres.

(2) The chemi-mechanical pulping process is a variation of the mechanical process where the wood is subjected to a chemical pre-treatment before the fibres are mechanically separated.

(3) Kraft pulping is a chemical process which uses sodium sulphate to digest the lignin and separate the wood fibre.

TABLE 3-18

ANNUAL CHIP SURPLUS, SOUTHEASTERN BRITISH COLUMBIA, BY SUPPLY UNIT

(GPU's)(1)

Supply Unit	Total Supply	Surplus at Current Pulping Capacity 100%	Surplus at Current Pulping Capacity 90%	Actual Surplus
Kamloops	875,000	225,000	290,000	320,000
West Kootenay	500,000	90,000	130,000	140,000
East Kootenay	370,000	55,000	85,000	55,000
Total	1,745,000	370,000	505,000	515,000

SOURCE: B.C. Ministry of Forests (1982d).

(1) The original source provided estimates in terms of BDU's. These have been converted to GPU's for consistency.

A possible new 300 mtpd cedar waferboard plant in the Kamloops or West Kootenay supply area was also identified as a potential fibre demand.

When existing chip and sawdust demands are added to these potential expansions, fibre requirements in the southeast area could total approximately 2,540,000 GPU's per year of chips and 400,000 GPU's of sawdust and shavings for fibre used.[1]

In the Kamloops region[2] sawdust and shavings production is estimated at 476,700 GPU's per annum from Crown timber harvests (B.C. Ministry of Forests, 1982d). Existing sawdust demand for pulping in Kamloops accounts for 250,000 GPU's; the potential expansions outlined above would also require sizable volumes. The apparent implication of this expansion would be a decline in available residues. However the expansion in pulp capacity is predicated upon increased harvests of decadent timber and currently underutilized species in the Kamloops Forest Region. Bringing this material into production would in turn generate more bark residues. The net effect of increased timber harvesting and increased utilization on mill residual surpluses cannot be predicted without more detailed analysis (B.C. Ministry of Forests, pers. comm.).

(ii) Energy Demand

In the Kamloops study area, there is a significant current demand for mill residuals for process heat. The Weyerhaeuser pulp mill operates a hog-fueled power boiler which accounts for the largest single demand for mill residuals.

Utilization of wood energy by the sawmilling industry has been generally restricted to those mills formerly dependent on the more costly fossil fuels, such as residual oil, diesel or propane. Sawmills in the Kamloops study

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(1) Based on added capacity of 450 mtpd of sawdust pulp requiring 2.5 BDU's of sawdust and shavings per ton of pulp and plant operation 345 days per year (see B.C. Ministry of Forests, 1982d). Figures have been derived on the basis of BDU's, but for consistency, GPU's are shown.

(2) Including the Kamloops, Okanagan and Merritt TSA's.

area with wood fueled kiln driers include Clearwater Timber Products and Weyerhaeuser in Vavenby, and Federated Co-op in Canoe. The Balco veneer plant in Kamloops also utilizes hog fuel in its veneer driers (B.C. Ministry of Industry and Small Business Development, 1980).

There are three areas of potential growth in use of mill wastes for energy in the Kamloops study region:

- the continued replacement of natural gas by wood energy in the sawmilling sector drying kilns;
- the potential new demands for boiler fuel created by future expansion of pulp capacity in southeast British Columbia, particularly in the Kamloops region; and
- opportunities for cogeneration within the forest industry.

There is considerable potential for the replacement of natural gas by wood energy in the sawmilling sector. A recent study for Inland Natural Gas indicates that conversion from natural gas to wood fueled kiln driers in sawmills appears viable in the near future (Levelton, 1982; see Appendix B for details). It seems likely that integrated firms already using hog fuel in another process are the most likely candidates for conversion (B.C. Ministry of Industry and Small Business Development, 1980). On that basis, potential candidates in the Kamloops study area include Weyerhaeuser's sawmills in Kamloops and Merritt, and Balco's Kamloops sawmill. Among veneer plants using natural gas fueled driers, the most likely candidates for conversion to wood fueled systems are those mills using log conditioning vats to prepare logs for peeling, including Evans Products in Savona and Federated Co-op in Canoe.

This potential energy demand for mill residuals by sawmills and veneer plants would be no means eliminate the excess supply of mill residuals in the Kamloops region. Only a fraction of an average sawmill's waste output is necessary to satisfy the typical energy demands of a lumber or veneer kiln.[1]

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(1) It has been estimated that planer shavings alone offer more than sufficient energy to kiln dry a mill's total output (B.C. Ministry of Industry and Small Business Development, 1980), and this was confirmed in industry interviews in Williams Lake.

Cogeneration in conjunction with wood-fired steam systems is also a potential energy demand which has been actively considered by at least one major firm in the Kamloops study region. Weyerhaeuser has studied the feasibility of small scale (10 MW) electrical generating plants at several sawmills to supply process steam for lumber kilns, and with the waste heat to generate electricity for the provincial power grid. Industry sources indicate that, as a rule of thumb, 8,000 GPU's of extra mill residue consumption are required to generate one MW of power on an annual basis. The scale of 10 MW cogeneration capacity would therefore require 80,000 GPU's per annum. However, as noted earlier, this option is constrained by B.C. Hydro's unwillingness to purchase cogenerated electrical energy at prices equal to its marginal generation costs, and its resistance to "wheeling" electrical energy from one plant to another.[1]

Finally, expanded pulp capacity in the Kamloops study area would also create new demands for mill residuals for energy. For example, the addition of a 900 mtpd kraft mill in the Kamloops region using a wood waste power boiler would create a new demand for mill residuals slightly less than the existing energy demand at Weyerhaeuser.

Energy demands for residues can be summarized by saying there is significant energy utilization at present in the Kamloops area, and considerable scope for increased demands. However, the exact volumes of potential energy use depend on a multitude of factors, including prices for alternative fuels and the scale of expansion in the pulp sector. Without extensive modelling, a detailed, quantitative estimate cannot be provided.

(d) Available Volumes and Costs

(i) Volumes

Three problems must be resolved in order to derive estimates of mill waste volumes available for alcohol production at Kamloops. These are:

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(1) "Wheeling" refers to using the utility's transmission system to move power from one industry plant to another plant for a transmission fee.

- the lack of an estimate of the total production of mill residues in the 200 km economic zone around Kamloops;
- the lack of a quantified estimate of all potential alternative fibre or energy uses for mill residues in this zone; and
- the lack of modelling capabilities to determine the highest valued uses of residues in the zone.

To overcome these information gaps, it was decided to employ data prepared by Weyerhaeuser Ltd. regarding the supply of bark residues available from sawmill centers around Kamloops. Since Weyerhaeuser is the only significant purchaser of mill residues in the Kamloops region, it seems reasonable to expect that the company likely has the most accurate and reliable data regarding the area's wood waste supplies.

Mill residue information derived from Weyerhaeuser's cogeneration feasibility study is shown in Table 3-19. These data refer to bark residues only, and so represent the minimum long-term quantities of residues that are available for energy use in a central facility. This approach was adopted in Weyerhaeuser's analysis because of the uncertainty over demands for clean residues as pulp furnish or for sawmill wood energy systems. Nevertheless, it is acknowledged by Weyerhaeuser and other sources (including the Ministry of Forests' regional office) that many components of mill residues in addition to bark are now wasted; consequently, the actual volumes of surplus residues currently available can be assumed to far exceed the figures shown in Table 3-19.

(ii) Scenarios of Availability

For purposes of this analysis, an estimate of all residues currently available for alcohol use has been interpolated from Weyerhaeuser's data. This estimate is shown in Table 3-20. It can be seen from the table that only two supply scenarios are developed for Kamloops: the "probable short-term" and the "minimum" cases. No "probable long-term" estimate was developed because of the range of uncertainties over alternative development and alternative uses of wood wastes in the region. By implication, the

TABLE 3-19

AVAILABLE BARK VOLUMES IN KAMLOOPS AREA BY PRODUCTION AREA

(ODt)

Production Area	Bark Volumes
Kamloops	55,000
Savona	15,000
Louis Creek	7,000
Barriere	11,000
Clearwater	13,000
Vavenby	70,000
Merritt	40,000
Adams Lake	20,000
Canoe	60,000
Armstrong	15,000
Lavington	44,000
Lumby	18,000
Total	368,000

SOURCE: Weyerhaeuser Canada Ltd.

"probable long-term" case can be assumed to equal the minimum case, which hypothesizes that only bark residues are available for long-term energy use in a central facility.

TABLE 3-20

SUMMARY OF SCENARIOS FOR KAMLOOPS AREA MILL RESIDUAL AVAILABILITY

Scenario	Description	Implicit Assumptions	Volume Available (ODt's)
I	Probable Short Term	Mill residual volumes roughly double current estimated bark surplus.	700,000
II	Minimum	Current bark surplus will persist. Alternative uses for fibre or energy purposes eliminate all other mill residual surpluses.	350,000

The "probable short term" case was derived by increasing Weyerhaeuser's estimate of bark residues in Table 3-19 by 100 percent. Although this ratio is admittedly arbitrary, some rationale for it can be found in Reid, Collins (1978) study which indicates that the average proportion of bark in typical Interior mill residue production is roughly 25 percent. Thus, the Probable Short Term case implicitly assumes that one half of all mill residues are utilized for fibre or existing energy needs, and the other half, including bark, is available for an alcohol plant.

For the cost analysis of an alcohol fuels plant, it is recommended that the "minimum" scenario be used to estimate long-term available wood waste supplies in the Kamloops area. Again, this conservative approach is predicated on the uncertainties over long-term alternative uses, and could considerably underestimate actual supplies.

(iii) Mill Residues Costs

Similar to the Williams Lake analysis, the relevant considerations are preparation and transportation costs, opportunity costs, and avoided disposal costs.

Preparation and Transportation Costs

It was previously established that preparation costs for "hogging" or crushing mill residues are usually required regardless of whether the material is sold to an energy user or burned in a disposal facility. Thus preparation costs are treated as a component of avoided disposal costs, and discussed later.

Transportation costs are an important issue for mill residue supplies in Kamloops, since the producing mills are widely distributed over the 200 km radius economic supply zone. Estimates of these costs were based upon information supplied by Weyerhaeuser (pers. comm.); current hog fuel transportation costs are estimated at $.25 per km per ODt. The distances from the supply sources listed in Table 3-19 to Kamloops were estimated by inspection of a provincial road map; these distances were multiplied by the volumes available and the unit transport costs to estimate the transport costs from each location to Kamloops. When all the sources are aggregated the result is an upward sloping supply curve plotting increasing quantities of residues in relation to increasing transportation costs. Over the 200 km economic zone, marginal transport costs range from $5.00 per ODt to $50.00 per ODt, with $29.00 per ODt the average transportation cost for the 350,000 ODt's identified in Table 3-20. Further details of transportation costs are provided in Appendix C. As discussed previously, these transportation costs are assumed to remain constant in real terms.

Opportunity Costs

Our approach to estimating available wood waste volumes omits from consideration any materials which could be required for alternative uses. Thus by implication the opportunity costs of materials assumed to be available for alcohol use are zero.

Avoided Disposal Costs

As noted for Williams Lake, avoided disposal costs are a potential benefit of utilizing for alcohol production mill residues that are currently wasted. In the Kamloops area this is a particularly important consideration because many mills do not have on-site burner facilities. Thus, there is an added disposal cost for transport of surplus material.

Where wastes are currently transported for disposal, this cost could potentially be considered as a credit against the cost of transporting mill residuals for use in an alcohol plant. Based on only a minimum haul length, this credit could reach $5.00 per ODt, or even more.[1] This amount could be viewed as the minimum marginal cost savings for mills without on-site burners.

For mills with on-site burners, it is again important to distinguish between the marginal and average costs of disposal as previously discussed for Williams Lake. Using the same figure as at Williams Lake, a potential credit of $3.00 per ODt could be generated for those mills where on-site burner operations could be eliminated.

As with the Williams Lake analysis, potential cost savings in waste disposal are not explicitly shown as a credit in supplying mill residues to an alcohol plant at Kamloops. This approach is adopted because of the uncertainties over transport distances and marginal compared to average cost savings, for different amounts of purchases. It should be noted, however, that these potential cost savings in disposal may well be considerably larger on average at Kamloops than at Williams Lake. Further detailed analysis would be necessary before making supply commitments.

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(1) Based on a minimal haul distance, with costs largely accruing for loading and unloading, as was shown for Quesnel residue production shipped to Cariboo Pulp and Paper.

(iv) Supply Curve for Mill Residues

In Figure 3-2, a supply curve is presented which relates increasing quantities to increasing costs for mill residues. The curve corresponds to the "Minimum" case scenario, in which only bark is assumed available for energy purposes over the long term. The costs and volumes presented in the figure can be assumed to portray the situation over the whole forecast period, with volumes and costs remaining constant.

If potential disposal cost savings were shown as a credit against other costs, the result would be illustrated by the supply curve shifting down and to the right, with costs lowered by $3 to $5 (at minimum) for each quantity. It is conceivable that the slope of the curve could decrease with greater savings at the more distant mills. This shape would be the case if more distant mills have a greater transportation component in their current disposal costs.

3.5 Marginal Sources of Supply

(a) Overview

One problem that plagues all bioenergy facilities planning to rely on sawmill residues is security of fuel supply. Because wood wastes are a costless by-product of sawmill operations, the supply of residue is completely dependent on the level of milling activity. A prolonged strike or period of slow demand for sawn lumber would mean that the flow of mill residues could slow or stop entirely. This is a difficulty that has long been recognized by pulp sector operations which depend on residues for boiler fuel. In 1975, McMillan Bloedel Ltd. commented:

> The hog fuel market is the most volatile, in terms of supply and demand, of all wood residuals. Most of the hog fuel produced is used by the forest industry for power generation, but some must be disposed of by burning and dumping.
>
> Hog fuel is a bulky, difficult and expensive commodity to handle. It deteriorates and poses a fire hazard during extended storage and large inventories are not commonly carried. Pulp mills, the major users, normally hold as little as one week's

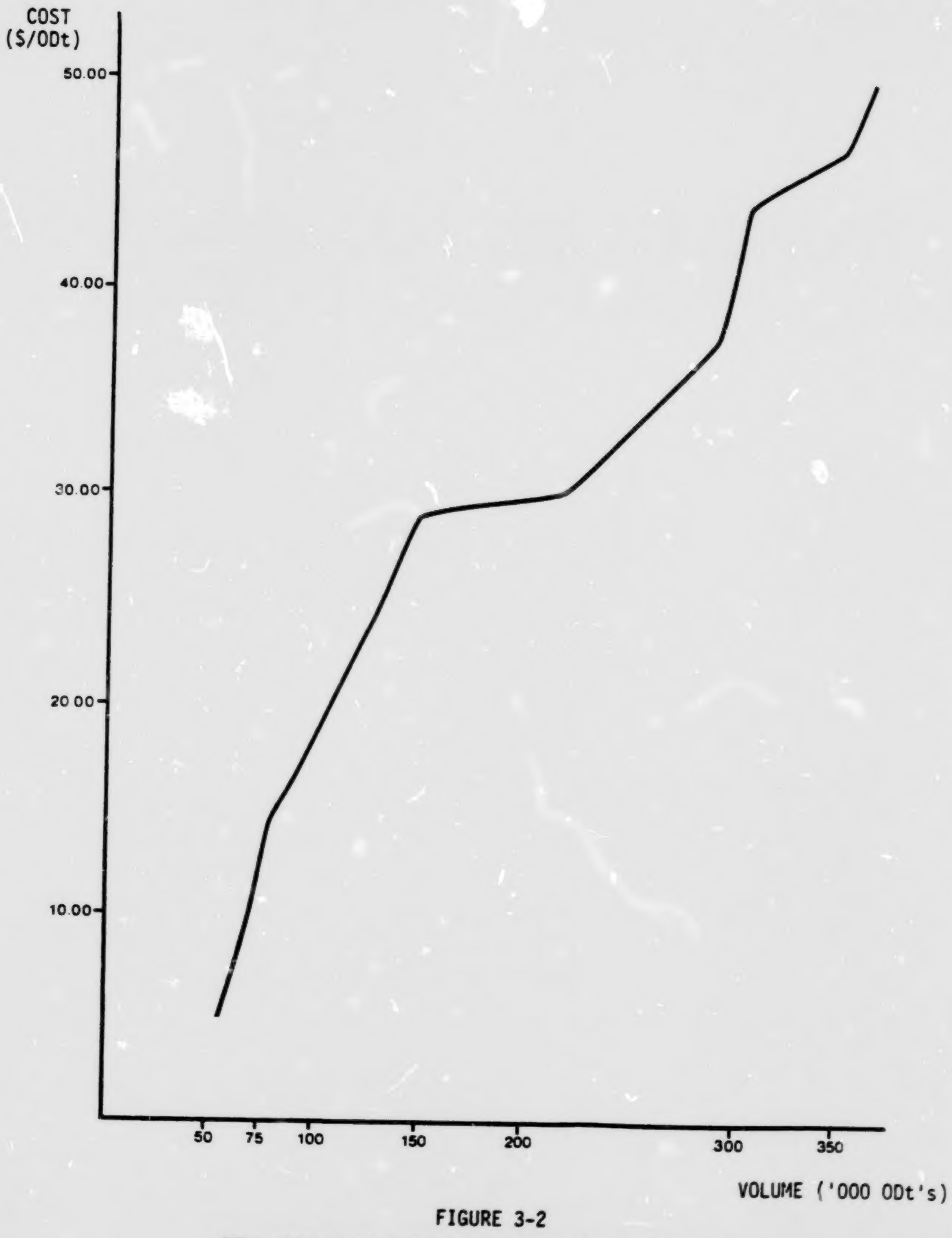

FIGURE 3-2
MILL RESIDUALS SUPPLY SCHEDULE FOR KAMLOOPS AREA

> supply in inventory, and any disruption in usage or supply quickly reflects on the market demand. Often these disruptions occur across the industry at the same time, so that surpluses or shortages become acute in a matter of days. (McMillen Bloedel, 1975)

In its study for the ENFOR Secretariat of the federal government, McDaniels Research Ltd. (1981) discussed the problems associated with consistency of supply for bioenergy facilities. Historical variations in the outputs of the pulp and wood products sectors were discussed to illustrate the vagaries in chip production and consumption, and the instability of fuel supplies experienced at a wood-fueled electrical plant in Eugene, Oregon was documented. The report emphasized the need for efficient markets for bioenergy fuels to attract new supplies during periods of shortages, or to reduce supplies during surpluses.

The conclusion to be drawn is that bioenergy facilities should attempt to minimize risks associated with their feedstock by having a number of alternative sources of marginal or higher cost biomass available to be utilized on a short term basis. Moreover the ability to utilize a back-up fossil fuel for feedstock may also be attractive for an alcohol plant.

In the following subsections, we discuss some of the marginal sources of biomass supplies that could be considered for an alcohol plant at Williams Lake or Kamloops. Unfortunately, some of the discussion is qualitative rather than quantitative in nature, although tentative costs and volumes for one marginal source, forest residue recovery, are provided. The final subsection briefly discusses possible institutional mechanisms that would be needed to obtain short term access to these marginal sources of supply.

(b) Marginal Sources of Supply

The marginal or supplementary sources of forest biomass supply that could be utilized on a short term basis by an alcohol plant would include:

- recovery of mill residues from existing landfill operations
- recovery of convenient yard or landing residues which could be chipped for fuel;

- recovery of forest residues from harvested areas which could chipped for fuel;
- harvesting or decadent, diseased or underutilized stands, which could be chipped for fuel.

In general, the more dispersed the source of supply, the more costly will be the biomass material. Thus the listing above is ordered from the least to most costly source, assuming equal transportation distances.

(i) Land-Filled Mill Residues

Published information suggests that wood residues stores in landfills may not greatly deteriorate in terms of potential energy content for some decades (Evans, 1976).[1] This brings to mind the possibility of "mining" landfills as a short-term marginal source of biomass. Discussions with forest industry spokesmen indicated that recovery of hog fuel from landfills is indeed feasible, and has already occurred in various locations, primarily on Vancouver Island. Two noteworthy examples are:

- British Columbia Forest Products is recovering hog fuel from a landfill at Cowichan on Vancouver Island for use in its pulp mill at Crofton;
- a hog fuel disposal site near Port Alberni has reportedly been reclaimed for energy use in the Port Alberni pulp mill.

There are also other examples of successful reclamation operations, which confirm the technical and economic feasibility of this marginal source. Interviews with two major forest industry firms in the south coast indicate that landfill reclamation is becoming recognized as a viable hog fuel supply source. There are certain problems to be overcome, such as the handling and loading processes, the high moisture content, and non-combustible trash mixed in the piles. However, these are common problems for most biomass

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(1) Interviews with forestry researchers confirmed this point. The main determinant of deterioration would be exposure to oxygen, so materials below the surface would be of higher quality (PPRIC, pers. comm.).

fuels, and can be surmounted given an appropriate economic incentive.[1]

It seems reasonable to assume that most wood products conversion centers in the province which now encounter waste disposal problems have one or more former landfill sites nearby. Although precise data are not at hand, interviews indicated that both the Williams Lake and Kamloops supply regions would have significant landfilled residues available. At Quesnel, a nearby supply source for Williams Lake, a landfill exists that contains several years' waste output from the six local mills. A conservative estimate would be that this dump contains the equivalent of at least 2 million ODt of mill wastes (that is, a minimum of 200,000 ODt per year for 10 years). This source could likely be relied on to supply the needs of an alcohol plant at Williams Lake whenever the normal flow of mill residues was interrupted.

It is safe to say that this potential supply source would require further engineering research, and a reliable estimate of volumes and costs for the particular location. As a rough estimate, one could assume that the costs would not exceed four times normal waste disposal costs; that would place costs at roughly $12 per ODt, excluding transportation. No data were available regarding the costs of residue recovery from existing landfill reclamation operations.

(ii) Recovery of Log-Sort and Yard Residues

Utilization of log-sort and yard residues in convenient locations would be the first step in recovery of energy biomass from forest residues. These convenient sources would be the first to be utilized because the material is already collected in central locations, and transportation costs would be low. One firm, FibreCo, has in the past recovered chips from yard residues for export as pulp furnish (McDaniels Research, 1981). Also, interviews with a major forest industry firm indicated that log yard residues could readily become a marginal source of biomass supply in the south coast region (BCFP, pers. comm.).

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(1) This information is derived from interviews with individuals from British Columbia Forest Products (BCFP), Canadian Forest Products, FERIC and Forestal International Ltd.

The costs of recovering energy biomass from yard residues can be interpolated from available studies. One report for the ENFOR program analyzed systems to recover logging residues (Forestal, 1980). That study estimated the 1980 costs of collecting and processing forest residuals to range from $42/ODt to $57/ODt, which could be reduced to perhaps $30/ODt with better machine efficiencies. A more recent report by FERIC regarding field studies for a mobile chipper indicated chipping costs of $7.72 per green tonne of biomass, or about $15/ODt (in 1981 terms), assuming no logging or transport costs (FERIC, 1982). Assuming that collection costs are minimal for log yard residues, then processing (chipping) costs could be estimated as roughly $15-$30/ODt in 1982 terms.

No data are at hand regarding the biomass volumes available from this source, but they can be assumed to be substantial in both the Williams Lake and Kamloops areas.

(iii) Forest Residues

Forest residues are a potentially large but high cost source of biomass materials in British Columbia. The "forest residues" term can refer to logging residues, intermediate-thinnings, dead trees or other materials. Logging residues are the most widely available residue form, being essentially waste tree portions left in the woods after commercial harvest. This source is likely the most abundant and lowest cost of forest residues and so is the focus here.

Volumes

A range of factors affect the volume of logging residues remaining at a specific location, including stand age and quality, nature of terrain, standards of utilization, market conditions and mill specifications. Because quantities of logging residues are so variable between sites, it is difficult to obtain estimates of the total amount produced. Different studies have attempted to estimate the volumes of logging residues occurring at various sites in British Columbia.[1] After a review of these studies, McDaniels

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(1) See F.L.C. Reed and Associates (1978), Mitre Corporation (1977), Pulp & Paper Research Institute (1975), and B.C. Forest Service (1976).

Research Ltd. (1981) made estimates of the volumes of logging residues produced in the various Forest Regions, based on 1978 data. These estimates reproduced in Table 3-21, refer only to merchantable logging residues, which fall within the Ministry of Forests' current utilization standards. The table indicates annual merchantable residues to be approximately 6.9 million ODt per year, the volumes of unmerchantable residues are likely to be at least that great.

Costs

More important than aggregate volumes are the costs of recovering logging residues in a form usable for energy purposes. Costs of processing residuals will vary substantially, depending on terrain, volume of material, size of pieces and method of retrieval. In general, larger pieces can be handled at lower costs.

In its ENFOR report, McDaniels Research Ltd. summarized the results of a number of studies which have attempted to estimate the costs of recovering logging residues under a variety of conditions with different handling systems.[1] The conclusion drawn was that costs could range below $30 to over $75 per ODt (1980) with $50 per ODt (excluding transportation) being a reasonable estimate of average costs of recovering larger residues (McDaniels Research, 1981). In 1982 terms, this figure amounts to roughly $60 per ODt.

Long-Term Considerations

It is important to note that the future availability of logging residues could be affected by a number of factors. They include:

- increasing real prices of forest products could mean fuller harvests of forest materials, up to the close utilization standards by the Ministry of Forests or even beyond. This trend would obviously reduce forest residues;
- the move to second-growth managed stands with uniform age and spacing would produce far fewer residues per hectare;

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(1) See P.H. Jones & Associates (1979), Forestal (1981) and Mitre Corporation 1977).

TABLE 3-21

PROJECTIONS OF MERCHANTABLE LOGGING RESIDUES FALLING WITHIN CLOSE UTILIZATION STANDARDS

1978

Forest District	Total Timber Scale, 1978 (1) (m^3)	Estimated Residue Factor (2)	Projected Residues (ODt) (3)
Prince George	13,880,000	.16	980,000
Kamloops	8,920,000	.18	710,000
Cariboo	7,510,000	.13	430,000
Nelson	7,220,000	.21	670,000
Prince Rupert Interior	5,240,000	.17	390,000
Prince Rupert Coast	4,110,000	.25	450,000
Vancouver	28,190,000	.26	3,230,000
Total	75,070,000		6,860,000

SOURCE: McDaniels Research Ltd. (1981).

(1) British Columbia, Ministry of Forests (1978). Total timber scale in 1978 exceeded the 10-year average by about 14,160,000 cubic metres.

(2) British Columbia Forest Service (1976). The factors shown above include those given for avoidable and unavoidable wastes of merchantable timber. The ratios shown for the Prince Ruper District were interpolated from the others, since none were given in the original source.

(3) It is assumed that 2.8 cubic metres is equivalent to 1.25 ODt.

- reliance on logging residuals for energy would essentially mean the supply sources would be continuously shifting outward to higher cost locations.

These factors, as well as the high cost of logging residues compared to mill residues, inhibit any long-term continuous reliance on logging residues for energy. On the other hand, use of these materials on a short-term basis to relieve temporary short falls in mill waste supplies may be practical.

(iv) Underutilized Species and Diseased or Decadent Stands

Reliance on these potential biomass sources would essentially entail harvesting trees not commercially viable for wood products and converting them to chips for energy. The costs of such operations would be similar to the range of commercial logging costs in British Columbia, and are too variable to be summarized here. Similarly, estimates of volumes of wood that could be available for energy purposes would require detailed region by region surveys and were not attempted for this study. One could expect that the costs would at least equal the figure identified earlier for logging residue recovery, that is, an average of $60 per ODt.

The chief reason that underutilized species and diseased or decadent stands are mentioned in this context is that there are certain silvicultural benefits associated with removal of these trees. Their harvest would allow replanting with healthy commercial softwood species. Indeed, the Ministry of Forests generally requires its licensees to remove decadent or diseased timber when they are found in areas of commercial harvest, even though there is little or no use for the material. Similarly, cutting of non-commercial species such as alder is occurring at some locations on Vancouver Island in order to improve sites for conifers, even though no use is made of downed wood.

The point to be made is that short-term utilization of these materials for energy purposes may make stand improvement measures more economically attractive. This topic is pursued further, and recommendations made to encourage implementation, in McDaniels Research (1981).

(c) Institutional Issues

Certain institutional changes or arrangements may be necessary to allow an alcohol plant access to these marginal sources of supply on a short-term basis. Two such institutional issues, the establishment of markets for biomass materials, and temporary licenses to harvest forest residues, are discussed below.

Markets

Given the uncertain nature of biomass fuel supplies, with wide swings in supply and demand, it seems that a mechanism to efficiently bring forth supplementary supplies in times of shortage or reduce supplies during surpluses would be valuable. Of course, the best mechanism of this type would be a smoothly functioning market. An alcohol plant could encourage the establishment of a market by obtaining only a portion of its biomass inputs through long-term contracts with sawmills. The remainder could be purchased on the open market from, say, three or four steady suppliers. During a period of biomass shortages, the price for biomass would increase and thus encourage the suppliers to bring forth residue supplies from more distant locations, or perhaps begin to recover waste materials from landfills. At other times, surpluses would mean the price tends downward, and marginal supplies would no longer be viable.

So long as the alcohol plant ensured that it had a number of competitive suppliers, there would be little reason to fear that the plant's biomass costs would be higher than with fixed supply and price contracts, or with outright control of biomass inputs.[1] Indeed, the alcohol plant would benefit from the competition between suppliers, and suppliers would bear the risks in acquiring marginal sources. Moreover, the structure of the market, with one purchaser and many suppliers, would show greater market power and influence over price for the purchaser.

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(1) See Schwindt (1977) for a discussion of the conditions which encourage backward integration and control over raw materials in processing industries when supplies are insecure.

Harvesting Licenses

If the price of mill residues is very high due to supply shortages, then an alcohol plant or its biomass suppliers may find it viable to recover logging residues or harvest defective stands for energy. In order to allow recovery of this material certain forest harvesting licenses or contracts would have to be established. Yet the licensee would probably want to exercise these licenses at its discretion, when mill residue prices are high. An obligation to steadily recover logging residues or harvest defective material would likely be unattractive to any enterprise at this time.

The Ministry of Forests would likely have to consider making available contracts to harvest defective stands or recover forest residues. Presumably no stumpage would be charged on these materials, and the contractor should have the option to not remove the material if it chooses. McDaniels Research (1981) discusses this issue and recommends that the Ministry of Forests consider establishing such contracts for bioenergy facilities.

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CHAPTER 4 - OVERVIEW OF METHANOL AND ETHANOL CHARACTERISTICS AND PRODUCTION ROUTES

4.1 Fuel Characteristics

A summary of fuel-related properties of methanol, ethanol, and gasoline are presented in Table 4-1 allowing comparison of the properties affecting the use of alcohols as a partial or complete substitute for engine gasoline. Of most significance initially is the relative magnitude of the lower heating value of the fuels. The data show that methanol and ethanol have a lower heating value on a volume basis of 49% and 66% of gasoline, respectively. For typical gasohol blends containing 10 vol % alcohol, the impact of this difference is relatively minor, though it becomes a significant design factor for automobiles designed for operation on pure alcohols.

Because of methanol's polar molecular structure, its solubility in gasoline is limited. For typical gasolines, the maximum blending concentration for anhydrous methanol is about 15%. Tests reported by Wigg indicate that the presence of only 1 vol % water results in the separation of a methanol-water phase from a methanol-gasoline mixture. A possible measure for reducing this problem is the addition of another component to increase the solubility of the water-methanol mixture in gasoline.

Ethanol/gasoline mixtures have a somewhat higher tolerance to water than methanol/gasoline blends. The concentration of water that can be tolerated in an ethanol/gasoline blend depends on the ethanol concentration, but for a typical concentration of 10 vol %, the water concentration should be less than about 1 vol % for abovezero temperatures. The allowable water concentration decreases rapidly with decreasing temperature.

TABLE 4-1

FUEL-RELATED PROPERTIES OF METHANOL, ETHANOL, AND GASOLINE

	Methanol	Ethanol	Typical Gasoline
Specific Gravity @ 20°	0.792	0.789	0.72-0.78
Composition, (wt %)			
Carbon	37.5	52.1	85-88
Hydrogen	12.5	13.0	12-15
Oxygen	50.0	34.9	
Heating Value @ 25°C, Fuel Liquid			
Higher Value (kJ/kg)	22,737	29,733	46,968
(kJ/l)	18,008	23,459	34,399
Lower Value (kJ/kg)	19,969	26,849	42,978
(kJ/l)	15,815	21,184	32,234
Flammability Limits (Vol %)			
Lower	6.7	4.3	1.4
Upper	36.0	19.0	7.6
Vapour Pressure @ 38°C	31	13.8	48-103
Latent Heat of Vapourization at 25°C (kJ/kg)	1,151	900	251
Stoichiometric Air-Fuel Ratio	6.45	9.0	14.7
Octane Number			
Research Octane	106-115	106-108	91-100
Motor Octane	88-92	89-96	82-92

Sources: Tillman, R.M.; North American Mfg. Co.

Alcohols may be used directly as fuels in suitably-designed internal combustion engines. Tillman has pointed out several problems that must be confronted for this case:

- Incompatability of alcohol fuels with common materials of construction, such as aluminum, magnesium, and zinc, as well as several gasket materials, vinyl, neoprene, viton, and nylon, falling within this category;

- Cold-starting difficulties at temperatures below about 0°C, although remedies for this have been found;

- Vehicle design modifications such as increased storage tank and fuel feed system capacity, increases in the compression ratio to 11 or 12:1 to benefit from the higher octane rating of alcohols, and alteration of pollution control devices;

- Modification of retail distribution equipment to avoid contamination with water, corrosion problems, fire hazards, and toxic effects of alcohol vapours;

- Fire hazards due to the flammability of the vapour space over storage tanks. This may be alleviated by increasing the vapour pressure nearer to that of gasoline.

Use of alcohols for transportation fuels has several advantages. They are clean-burning, have the potential with proper engine design to achieve higher engine efficiency and power output, and are environmentally acceptable. One advantage that has been found from testing is the substantially lower NO_x emissions of straight alcohol engines compared to gasoline engines (Paul, J.K.).

4.2 Alternative Production Routes

The fundamental processing steps for the production of methanol from wood are shown in Figure 4-1. Gasification, using one of several processes, converts the wood to a synthesis gas rich in hydrogen and carbon monoxide, preferably in the proportion of slightly greater than 2:1 to promote the reaction,

$$CO + 2H_2 \longrightarrow CH_3OH,$$

which is strongly exothermic. The other major reactions for methanol synthesis are:

$$CO_2 + 3H_2 \longrightarrow CH_3OH + H_2O$$

and

$$CO + H_2O \longrightarrow CO_2 + H_2$$

Several undesirable side reactions may also occur in the catalyzed methanol synthesis reactor, some being:

$$CO + 3H_2 \longrightarrow CH_4 + H_2O$$
$$2CO + 4H_2 \longrightarrow C_2H_4 + 2H_2O$$
$$2CH_3OH \longrightarrow CH_3OCH_3 + H_2O$$

No gasification processes produce a gas suitable for direct synthesis to methanol, so steps must be taken to clean the gas to remove unacceptable concentrations of particulate matter, tars and oils, and subsequently, to modify the gas composition to produce the desired H_2:CO ratio and remove gaseous diluents and contaminants. Methanol synthesis proceeds over a catalyst at a pressure of 5,000 to 10,000 kPa and a temperature of 200 to 300°C.

The crude methanol condensed from the synthesis reactor must be purified to remove water, higher alcohols, and dissolved gases, resulting in a final methanol typically having a purity in excess of 99%.

Methanol plants in commercial operation use natural gas feedstock which is reformed to hydrogen and carbon monoxide approximately in

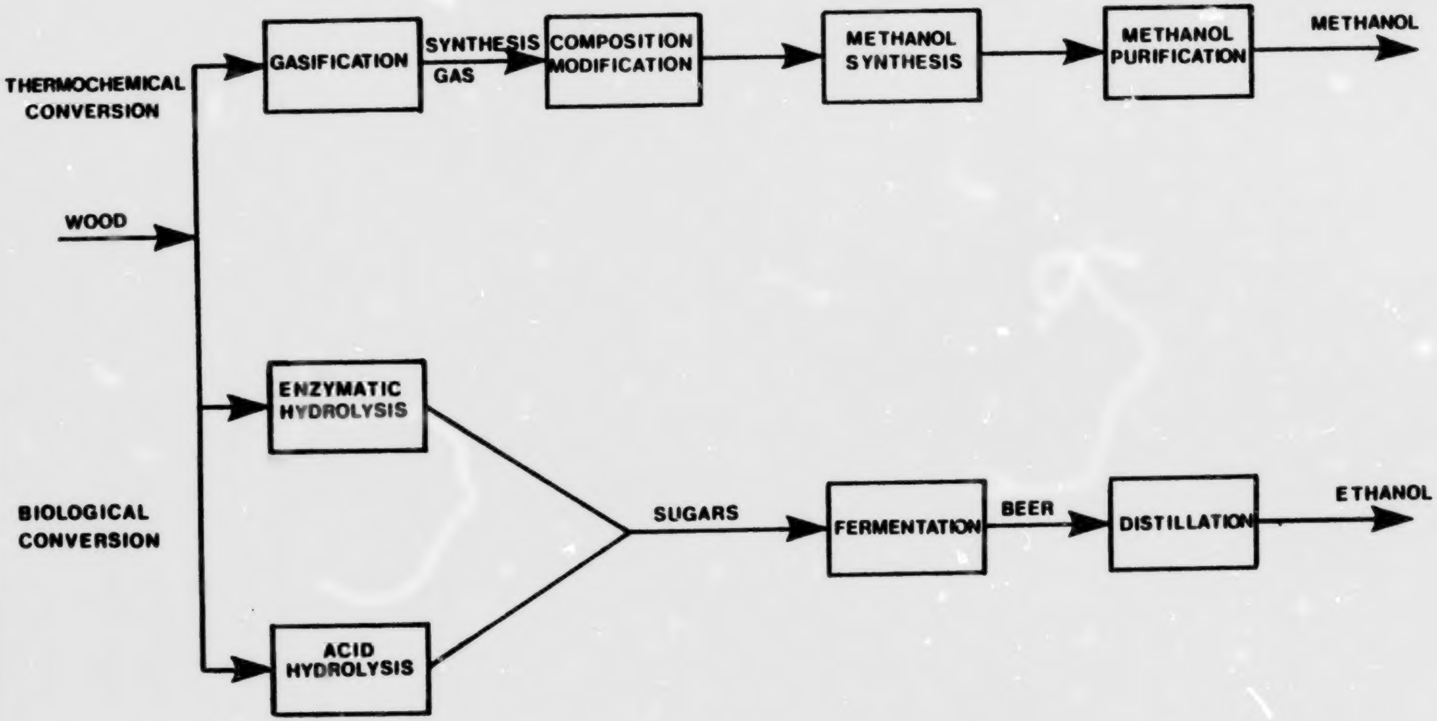
THERMOCHEMICAL CONVERSION
WOOD
BIOLOGICAL CONVERSION
GASIFICATION
SYNTHESIS GAS
COMPOSITION MODIFICATION
METHANOL SYNTHESIS
METHANOL PURIFICATION
METHANOL
ENZYMATIC HYDROLYSIS
ACID HYDROLYSIS
SUGARS
FERMENTATION
BEER
DISTILLATION
ETHANOL

FIGURE 4-1 LIQUID FUELS FROM WOOD BY BIOLOGICAL AND THERMOCHEMICAL PROCESSING

the proportions of 2:1. For both the traditional and wood feedstock plants, processing units must be highly integrated to maximize heat recovery and, consequently, plant thermal efficiency. Methanol plants using a natural gas feedstock (92% CH_4) have a plant efficiency ranging from 60% to 67% (Pettman and Humphreys), while those considered in engineering studies for a wood feedstock have efficiencies of 47% to 51%, based on the higher heating value of the produced methanol. For comparison, the efficiency of a plant using a coal feedstock has a predicted value of 59% (Rowell and Hokanson).

Through biological conversion using either enzymatic hydrolysis or acid hydrolysis, wood may be converted into ethanol and several by-products such as furfural, methanol, gypsum, and yeast. The type of by-products depends on the hydrolysis process that is used.

The acid hydrolysis process utilizes acid to convert cellulose into fermentable sugars, primarily hexoses such as glucose, with some pentoses. The degree of conversion of the cellulose content of wood to fermentable sugars is highly sensitive to the proportion of lignin present. The yield of fermentable sugars is a function of the species as well as the operating conditions of the hydrolysis reactor. The maximum theoretical yield of glucose from cellulose is 111% by weight. Therefore, wood containing 45 to 50% cellulose by weight theoretically will yield 50 to 55% glucose by weight. Typically, yields of 65% of the theoretical value are achieved in practise, resulting in glucose yields of 32.5% to 36%. Theoretical pentose sugar yields range from 6% for softwoods to upwards of 25% for hardwoods, based on the weight of dry wood. These sugars are not fermentable using traditional technology, although numerous developers are undertaking the development of microorganisms to enable fermentation to ethanol, resulting in a significant increase in fermentable sugar yield from wood.

The enzymatic hydrolysis process uses enzymes to produce fermentable sugars from wood pretreated to increase the availability of cellulose. Steam pretreatment involves exposing the wood to high pressure for a short period of time, with or without the addition of a small amount of acid, followed by a sudden release of this pressure, resulting in destruction of the wood structure and production of a subfibrous, finely-divided material. Lignin and hemicellulose are subsequently removed chemically from the pretreated wood to produce a cellulose for enzymatic hydrolysis.

Enzymatic hydrolysis has the potential for greater conversion of the cellulose to sugars, given that this material is available to enzymes. Stone and Marshall summarized work done with steam pretreated poplar and Rutgers C-30 strain enzyme, showing cellulose conversion of 80% to 90% has been achieved in 3- to 4-hour laboratory tests. These values exceed values of about 75% that have been observed for pilot plant tests (Stone).

Following hydrolysis by either process, the sugars are converted to a crude ethanol by fermentation in continuous or batch reactors. The fermentor product normally is limited to below 10% concentration because of the inhibiting effect of alcohol on yeast survival. Several developments are being pursued to maximize the alcohol content of the crude ethanol, thereby reducing distillation energy requirements.

In practice, the conversion of glucose to ethanol approaches the theoretical value of 51% by weight; typically being between 48% and 49%, due to sugar consumption during yeast cell growth (Stone). Yeasts do not normally ferment pentoses to ethanol, although of micro-organisms suited to this task are being developed and tested. Fermentation of pentoses would increase ethanol yields significantly, especially for hardwoods which yield pentoses by hemicellulose hydrolysis.

On a weight basis, the normal yield of ethanol from wood using conventional acid hydrolysis is about 16% to 20%. This is equivalent to an energy conversion efficiency of 24% to 30% on the basis of feed and product higher heating values. For enzymatic hydrolysis, the conversion efficiency increases above that of the acid hydrolysis case, assuming that glucose yields of 80% to 90% of theoretical prove to apply for commercial-scale systems. The yield of ethanol for this case may range from 19% to 24%, depending on wood species and the conversion efficiency of the hydrolysis and fermentation processes.

All energy required by ethanol production processes can be supplied by lignin removed after hydrolysis, which amounts to 20% to 30% by weight of the original wood. Because of the higher conversion efficiency of an enzymatic hydrolysis-to-ethanol plant, a slightly greater plant energy efficiency may be achieved compared to an acid hydrolysis-to-ethanol plant.

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CHAPTER 5 - PRODUCTION OF METHANOL

5.1 Gasification Options for Wood Feedstocks

The conventional feedstock for current commercial methanol plants is natural gas which can readily be reformed into the desired synthesis gases, carbon monoxide and hydrogen. To use a wood feedstock for methanol production, a gasification process is needed to produce a gas rich in the desired synthesis gases, and that can be cleaned and upgraded to essentially the same quality as the synthesis gas produced from natural gas. Several gasification processes appropriate for this are under development. A comprehensive list of the gasification routes, process characteristics, and developers is presented in Table 5-1.

Two generic gasification processes are evident from the list of developers, these being oxygen-fed and nonoxygen-fed (usually steam) gasification. In the case of oxygen-fed processes, some steam or carbon dioxide may be used to augment the oxygen stream with the intention of modifying or improving the gasification process. The most prominent reactor configurations for oxygen-blown processes are fixed-bed, fluidized-bed, and entrained-bed designs. All of these designs are under development for operation with coal at elevated pressure, but only the fluidized-bed design is presently being tested for operation at elevated pressure with a wood feed. Steam gasification processes have, to date, concentrated on stirred-bed (Wright-Malta) and fluidized-bed reactor configurations. The multiple-bed gasification process uses a steam-fed fluidized-bed wood gasifier and an air-fed fluidized-bed char combustor coupled together to yield a synthesis gas. Both fluidized-beds operate using sand entrained in the reagent gases to produce the desired level of fluidization of feedstock and to simultaneously act as a

TABLE 5-1

SUMMARY OF BIOMASS GASIFICATION PROCESSES

Gasification Route/Supplier	Operating Condition	Product Characteristics	Development Status
Oxygen Gasification			
Fixed-Bed			
- Purox	0.1 MPa, 1650°C	10% CH_4^+, Tar, $H_2/CO=0.69$	Commercial
- Wellman-Galusha	0.1 MPa, 1315°C	4% CH_4, Tar, $H_2/CO=0.68$	Commercial
- SERI	0.1 MPa, 930°C	4% CH_4, $H_2/CO=0.78$	PDU
- Davy	0.1 MPa, 1100°C	$H_2/CO=0.9$	Commercial
Fluidized-Bed			
- Winkler	1 MPa, 970°C	0.5% CH_4, $H_2/CO=1.11$	Commercial
- OMNI	1 MPa, 730°C	16% CH_4, Tar, $H_2/CO=0.48$	Pilot
- U. of Missouri	N/A	N/A	Pilot
- Texas Tech.	0.1 MPa, 815°C	10% CH_4, $H_2/CO=1.01$ Tar	PDU
- IGT	N/A	N/A	Bench
Entrained-Bed			
- Koppers-Totzek	0.1 MPa, 980°C	0.3% CH_4, $H_2/CO=0.81$	Commercial
- Georgia Tech.	N/A	N/A	Bench
Nonoxygen Gasification			
Steam Catalytic			
- Pacific Northwest	1 MPa, 750°C	4% CH_4, $H_2/CO=2.0$ Char, Tar	Pilot
- Wright-Malta	1 MPa, 540°C	9% CH_4, $H_2/CO=5.6$ Char, Tar	Pilot
Multiple-Bed			
- Battelle Columbus Lab	0.1 MPa, 870°C	9% CH_4, $H_2/CO=0.43$ Tar	Pilot
- Environmental Energy Eng.	0.1 MPa, 980°C	15% CH_4, Tar, $H_2/CO=0.54$	Pilot

heat-transport media. Char carried out of the gasifier with the sand is recovered and used for fuel in the combustor.

The two generic gasifiers, oxygen-blown and steam-blown, produce crude synthesis gases that, because the gas characteristics are sufficiently different, require different processing steps prior to methanol sythesis. An indicator of the extent of modification of these crude synthesis gases that is needed is the molar ratio of hydrogen to carbon monoxide. Data for the various gasification processes (Table 5-1) indicate that all fixed-bed, one fluidized-bed, and one entrained-bed oxygen-blown gasifiers have H_2/CO ratios of fixed gases well below the desired value of about 2.1. Of these, ones with high CH_4 contents could enhance the H_2/CO ratio by reformation of methane to hydrogen and carbon monoxide. The H_2/CO ratio for steam gasification processes are significantly higher and from experimental data, appear to meet or exceed the desired value.

Gasifiers may be operated at elevated or atmospheric pressure. Although feeding of pressurized gasifiers is prone to problems, several advantages such as reduced reactor size, improved chemical reaction rates, and a potentially superior crude synthesis gas composition make such a design attractive. For gasification at atmospheric pressure, the crude synthesis gas must be compressed to levels acceptable for subsequent reforming, shift conversion (as justified), and methanol synthesis.

5.2 Feedstock Options

The crude synthesis gas produced by most wood gasification processes is deficient in hydrogen needed for the methanol synthesis reactions:

$$2CO + 4H_2 \longrightarrow 2CH_3OH$$
$$3H_2 + CO_2 \longrightarrow CH_3OH + H_2O$$

For gas very low in carbon dioxide, the requisite H_2/CO ratio is 2:1, while for gases having a $CO:CO_2$ ratio of 2:1, the $H_2/(CO + 1.5CO_2)$ is 2:1. Wood-derived synthesis gases have a H_2/CO ratio normally within the range 0.5 to 1.0.

To increase the H_2/CO ratio of wood-derived synthesis gas to the level required, there are a number of processing options. If no gas additions from external sources are desired, then the required H_2/CO ratio may be achieved by shifting carbon monoxide with steam according to the reaction,

$$CO + H_2O \longrightarrow CO_2 + H_2.$$

This process leads to a concommitant increase of the CO_2 concentration with the H_2 concentration, making it necessary to remove excess CO_2 from the product gas. Most proposed plants for producing methanol from wood utilize a shift conversion step.

One alternative to shift conversion is the addition of hydrogen to the gas. This route was adopted for the study of methanol production from wood by Intergroup Consulting Economists that considered use of a Purox oxygen-blown gasifier. For this case, the hydrogen content of crude synthesis gas from the gasifier was increased by reforming the methane present and by adding hydrogen, resulting in an increase of $H_2/(CO + 1.5CO_2)$ from 0.33:1 to 2.05 to 2.1:1. Hydrogen was generated using an electrolysis process and was consumed at the rate of 0.12 t/t methanol or, equivalently, 0.13 t/t dry wood. The wood requirement was 0.91 ODt/t methanol. Since electrolysis leads to production of 8 t of oxygen for every tonne of hydrogen, the gross oxygen generation to match the hydrogen supply and demand was 0.96 t/t methanol. This oxygen supply is in excess of the requirement for gasification by 0.72 t/t methanol. This oxygen would be suitable for commercial sale.

The addition of hydrogen to the crude synthesis gas from the Purox gasifier considered by Intergroup reduced the wood requirement from

2.3 ODt/t methanol (for the wood-only case) to 0.91 ODt/t methanol, equivalent to an increase in yield of methanol from 0.43 t methanol/ ODt wood to 1.1 t methanol/ODt wood, an increase of 156%.

Another source of hydrogen for augmenting the hydrogen content of a synthesis gas is methane. In this case, hydrogen gas is obtained by reforming natural gas with steam at about 815°C as follows:

$$3CH_4 + 4H_2O \longrightarrow 2CO + 10H_2 + CO_2.$$

This is the initial processing step for the traditional use of methane for methanol synthesis. The resulting gas has a $H_2/(CO + 1.5CO_2)$ of 2.86:1, a value in excess of that required for methanol synthesis. This gas may be used to supply the hydrogen needed to bring the $H_2/(CO + 1.5CO_2)$ of wood-derived synthesis to the required level. The proportion of methane feedstock to wood feedstock needed to make up a gas suitable for methanol synthesis depends on the hydrogen and carbon oxides content of the crude synthesis gas exiting the gasifier.

Rock has considered a methane and wood hybrid methanol plant based on the Davy fixed-bed oxygen-fed gasifier having a crude synthesis gas with an $H_2:CO:CO_2$ ratio of 1.8:2:1. Under optimal conditions, 4.8 moles of this gas combine with 22.53 moles of reformed natural gas to give 8.2 moles of methanol. Processed separately, the methanol yield would be 1.27 moles from wood and 5.2 moles from methane for a total of 6.47 moles. The difference between this methanol yield and the total for the hybrid design, 8.2 moles, is due to the formation of methanol using the excess hydrogen yielded by reforming methane. This hydrogen normally forms part of the gas stream purged from the methanol synthesis reactor and burned to supply heat in the reformer. Consequently, the purge gas feed to the reformer must be supplemented with natural gas.

For the same methanol output, Rock has estimated that a hybrid methanol plant would require 25% less natural gas for feedstock and fuel than for a plant using natural gas only. This is in agreement with a comparison of the methane feedstock and fuel requirements calculated by Intergroup for a hybrid methanol plant using a Purox gasifier of 723 m^3/t methanol and the typical methanol plant feedstock and fuel requirement of 1,008 m^3/t methanol (Pettman and Humphreys). The feedstock and fuel requirements of plants with features for improved energy recovery may be as low as 905 m^3/t methanol.

The wood requirement of the hybrid plant considered by Intergroup was 0.38 ODt/t methanol (total methanol output), compared to the wood-only case of 2.3 ODt/t methanol. With the Davy gasifier, the wood requirement for the hybrid case is 0.39 ODt/t methanol.

5.3 Process Components

(a) Gasification

Gasifiers for converting wood or other biomass materials to synthesis gas are presently in various stages of development. Some of these gasifiers have been developed and demonstrated for coal gasification and have only recently been considered for wood feedstock because of the current interest in fuel-grade methanol produced from biomass fuels. Other designs have evolved from similar ones developed for converting wood into low-heating-value gas to be used directly for heating. Improved gasification processes are currently under development at several research and development laboratories in the United States and elsewhere.

A summary of developers of gasification processes, the operating performance of these processes, and some specific factors pertinent to assessing their suitability for producing syngas for methanol synthesis are given in Table 5-2. The Koppers-Totsek, Winkler, and Wellman-Galusha gasifiers were developed for coal, and for this feedstock, can be considered as commercial units. Although not

TABLE 5-2

SUMMARY OF GASIFIER PERFORMANCE

Developer	Battelle Columbus[1]	Omnifuel[2]	PNL[2]	Texas Tech[1]	Winkler[1]	Koppers-Totzek[1]	Wright-Malta[1]	Purox[2]	SERI[1]	Wellman-Galusha[2,3]
Gasifier Type	Dual Fluidized-Bed	Fluidized-Bed	Fluidized-Bed	Fluidized-Bed	Fluidized-Bed	Entrained-Bed	Stirred-Bed	Fixed-Bed	Fixed-Bed	Fixed-Bed
Biomass Feed	Wood @ 10% MC	Wood @ 10% MC	Wood @ 10% MC	Wood @ 10% MC	Wood @ 10% MC	Wood @ 10% MC	Wood @ 45% MC	Wood @ 25% MC	Wood @ 10% MC	Wood @ 10% MC
Steam (kg/kg Dry Wood)	0.301	N/A	0.75	0.42	0.180	0.026	--	—	—	0.41
Oxygen (kg/kg Dry Wood)	—	N/A	--	0.16	0.458	0.559	—	0.30	0.496	0.53
Pressure (kPa)	101	1830	1030	101	1010	101	1144	101	101	101
Temperature (°C)	870	870	750	815	970	980	540	930	600	N/A
OUTPUT										
Raw Gas Composition, Vol. %										
H_2	10.5	21.4	35.4	31.2	32.6	28.6	16.9	16.0	23.7	28.3
CO	24.7	45.2	19.6	28.5	29.2	35.2	3.0	26.5	45.2	41.6
CO_2	8.8	17.7	15.3	21.9	19.2	15.2	24.8	15.9	12.8	18.7
CH_4	8.9	15.7	8.8	9.1	0.5	0.2	13.3	3.7	3.5	3.7
C_2H_4	2.9	—	--	2.0	--	--	—	1.4	—	—
C_2H_6	0.3	—	--	0.8	--	--	2.4	3.8	—	—
H_2O	43.9	N/A	20.9	6.5	18.5	20.8	39.6	32.7	14.0	7.6
Carbon Conversion in Gas %	83	N/A	100	93	100	100	93	100	100	N/A
Wet Gas Yield, m^3/kg, 15°C, 101 kPa Dry Wood	1.35	N/A	2.29	1.30	1.96	1.12	1.88	1.96	1.73	N/A
Dry Gas Yield, m^3/kg, 15°C, 101 kPa Dry Wood	0.76	N/A	1.81	1.21	1.61	1.12	1.13	1.32	1.48	1.56
H_2/CO	0.43	0.47	1.81	1.09	1.12	0.81	5.6	0.60	0.52	0.68
CO/CO_2	2.81	2.55	1.28	1.30	1.52	2.32	0.12	1.67	3.53	2.22

[1] Experimental data

[2] Predicted

[3] After cooling to 40°C

presented in the summary table, the Davy Corporation markets commercial fixed-bed coal and wood gasifiers using steam and air or oxygen as the gasifying media. The Davy Corporation also supplies Winkler and Texaco gasifiers under license. Davy has conducted design work for a company in Brazil to specify an oxygen-blown fixed-bed gasifier suitable for Eucalyptus wood. Unfortunately, no performance data for an oxygen-blown Davy wood gasifier could be obtained.

Very limited development work has been conducted to adapt commercial coal gasifiers to wood feedstock. For this reason, these gasifiers are considered to be of pilot or near-commercial status, pending further demonstration with wood feedstocks.

Companies presently developing wood gasifiers for production of synthesis gas that can be considered of pilot status are the Wright-Malta Corporation and the Omnifuel Gasification Systems Ltd.

The remaining gasifiers listed in Table 5-2, Pacific Northwest Laboratory (PNL), Solar Energy Research Institute (SERI), Texas Tech University, and Battelle Columbus Laboratories, are those of advanced design and being developed under the United States Department of Energy biomass program. All these units are primarily for research and development purposes, although the PNL and BCL units can be considered as being of pilot scale.

Numerous performance characteristics of a gasification process must be considered when selecting one to produce synthesis gas from wood suitable for methanol production. Preferred performance characteristics for a wood gasifier producing synthesis gas are given in Table 5-3. Critical selection parameters are the H_2/CO ratio and the energy conversion efficiency. Gases having hydrogen and carbon monoxide ratios near that required by methanol synthesis and low in hydrocarbons and contaminants require minimal cleanup and modification for methanol synthesis. As seen from Table 5-2, few gasifiers

TABLE 5-3

PREFERRED GASIFIER PERFORMANCE CHARACTERISTICS FOR METHANOL SYNTHESIS

Gasifier Characteristiscs:

- Gas composition with a H_2/CO ratio over 2.0.
- Elevated synthesis gas pressure to reduce compression power requirements.
- Particulate matter, sulphur, chlorine, and condensible hydrocarbons at very low concentrations.

Process Performance:

- High thermal and energy conversion efficiency.
- High gasification capacity per unit area or volume.
- Relatively simple operation and low maintenance of equipment.
- Proven performance with wood.

Wood Handling:

- Accept wood feed at near its natural moisture content.
- Gasify feed having coarse and nonuniform particle sizes.

Costs:

- Low capital and operating costs.

developed to date have initially satisfactory hydrogen and carbon monoxide concentrations. In addition, most gases require considerable gas cleanup to remove particulate matter, catalyst poisons such as chlorides and sulphur, and condensible tars and oils. High levels of methane (such as for Wright-Malta) and higher paraffins in the synthesis gas warrent reforming of this gas to hydrogen, carbon monoxide, and carbon dioxide immediately after gas cleanup or after discharge from the methanol synthesis process in a purge stream to maximize the yield of methanol. The yield of methanol is very dependent on the total plant design and is not a simple function of the gasifier gas composition.

This study was to concentrate on near-commercial technology for the production of methanol from wood. Due to the large number of gasification systems under development for wood and the lack of commercial operating experience for all gasifiers producing synthesis gas, only those gasifiers deemed to be of near-commercial status and having performance characteristics that are attractive for methanol production were considered as possible candidates.

A thorough examination of the combination of wood gasification and methanol synthesis has been conducted by Science Applications Inc. (Wan, et al 1979, 1981, and 1982). Thermal efficiencies of the methanol plants and the total production costs for fuel-grade methanol as predicted by these studies are summarized in Table 5-4. From these data, it can be concluded that catalyzed steam gasification of wood for methanol synthesis leads to a slightly lower methanol production cost and a higher overall energy conversion efficiency. The improved energy conversion efficiency compared to the oxygen-blown gasifiers is due to the energy saved by not using an oxygen plant. Also of interest is oxygen-blown fluidized-bed gasification exemplified by the Winkler and Texas Tech processes. Pressurized operation of the gasifier reduces the compression power needed to raise the synthesis gas to methanol synthesis pressure, and consequently leads

TABLE 5-4

COMPARISON OF PLANT THERMAL EFFICIENCIES AND METHANOL PRODUCTION COSTS (MID 1981) FOR A SELECTION OF WOOD GASIFIERS

Developer	SERI	Winkler	Texas Tech	Battelle Columbus	Battelle Pacific Northwest	Koppers-Totzek	Wright-Malta
Gasifier Type	Fixed-Bed, Downdraft	Fluidized-Bed	Fluidized-Bed	Dual Fluidized-Bed	Fluidized-Bed	Entrained-Bed	Stirred-Bed
Pressure (kPa)	101	1100	101	101	1030	101	1140
Gasifying Agent	oxygen	steam & oxygen	oxygen	steam	steam & catalyst	steam & oxygen	steam & catalyst
Methanol Production (t/d)	450	450	450	450	450	450	450
Wood to Gasifier (ODt/d)	760	846	911	1150	595	632	909
Wood to Plant (ODt/d)	1305	1217	1219	1327	1038	970	1092
Total Plant Capital (U.S.$ X 10^6)	94.37	99.64	91.68	94.68	78.96	106.08	99.64
Annual Operating and Maintenance Cost, Excluding Feedstock (U.S.$/l)	0.05	0.06	0.05	0.06	0.06	0.05	0.05
Capital Charges (U.S.$/l)	0.13	0.14	0.13	0.13	0.11	0.15	0.11
Feedstock Cost @ $27.60(U.S.$/l)	0.06	0.06	0.06	0.06	0.05	0.07	0.06
Methanol Selling Price (U.S.$/l)	0.24	0.26	0.24	0.25	0.22	0.27	0.22
Overall Energy Conversion Efficiency (%)	39.9	44.4	42.7	39.3	50.2	42.3	47.7
Overall Carbon Conversion Efficiency (%)	24.6	28.6	27.6	25.3	32.4	26.7	30.8

to a slightly higher thermal efficiency than for nonpressurized operation. Pressurized operation results in a higher total plant cost and methanol production cost. The pressurized oxygen-blown fluidized-bed gasifier being developed by Omnifuel Gasification Systems Ltd. is being designed to operate at 1,826 kPa, a value higher than the pressure used for the Winkler process. In general terms, the Omnifuel gasifier is expected to have similar overall performance to the Winkler gasifier.

Based on the current status of the various gasification processes and the analyses of methanol plants done by Science Applications Inc. (Wan, et al 1981 and 1982), two candidate systems were chosen for further discussion; one being the Wright-Malta stirred-bed process, the other being the Omnifuel oxygen-blown fluidized-bed process.

(i) Omnifuel Gasification Systems Ltd.

Omnifuel has a commercial air-blown, fluidized-bed wood gasifier (Figure 5-1) installed at Levesque Plywood Ltd. in Hearst, Ontario, supplying low heating value gas (typically 5.6 MJ/m^3) for direct combustion in several oil heaters. Wood is discharged into this unit using a proprietary feeder produced by Stake Technology Ltd. that discharges into the bed against a moderate back pressure of about 35 kPa (gauge). Fuel gas is discharged at 17 kPa (gauge) and cleaned of particulate matter with two refractory-lined cyclones. Some of the sensible heat is used to heat inlet air. The gasifier has an energy output of near 63 GJ/h from a feed of 84 GJ/h of wood chips, hogged bark and plywood trim, and sawdust fed at near 30% moisture content, wet basis. The unit has been operated since May, 1981.

Omnifuel is presently under contract to Biosyn of Montreal to design a single oxygen-blown, fluidized-bed gasifier for producing

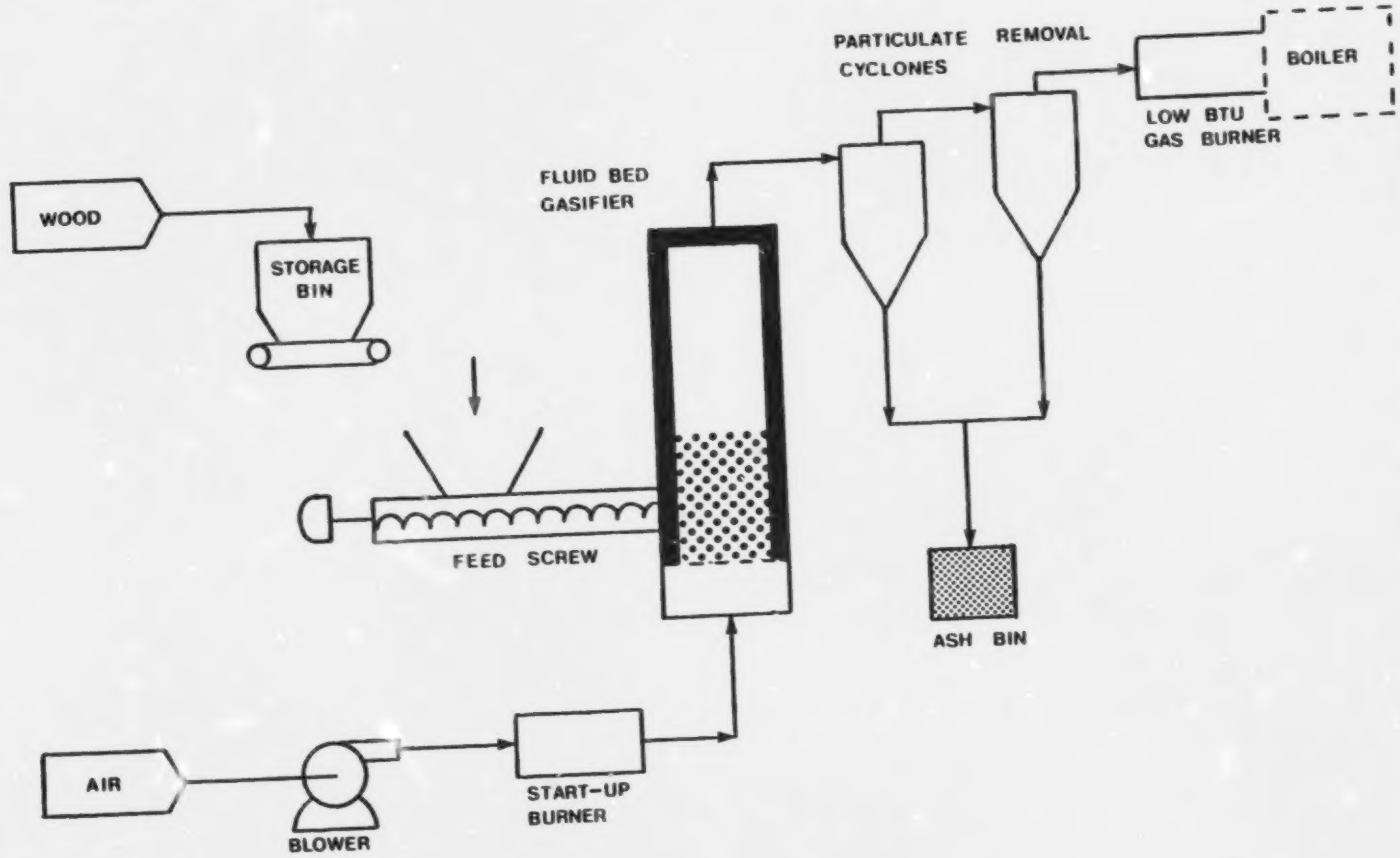

PARTICULATE REMOVAL
CYCLONES
BOILER
LOW BTU
GAS BURNER
FLUID BED
GASIFIER
WOOD
STORAGE
BIN
FEED SCREW
ASH BIN
AIR
BLOWER
START-UP
BURNER

FIGURE 5-1 LAYOUT OF AIR-BLOWN OMNIFUEL GASIFICATION SYSTEM

synthesis gas. The unit will be for demonstrating the technology, and is sized for a feed of 240 ODt/d of dried wood wastes and peat. The gasifier will operate at 1,830 kPa and at a bed temperature of near 870°C, and will probably utilize three feeders. Total funding for the project is presently set at $15 million, with contributions coming from Nouveler, Canertech, and Energy, Mines and Resources Canada. After successful demonstration of the gasifier, a methanol synthesis train is to be installed to demonstrate an integrated methanol-from-wood system. A preliminary methanol plant schematic diagram is shown in Figure 5-2.

The dry crude synthesis gas from the gasifier is expected to have near the composition given in Table 5-5 (Black, 1980, 1982). A similar gas composition has been reported by Inco Metals Co. from tests of a fluidized-bed gasifier operated near atmospheric pressure using hammermilled poplar wood with a moisture content of 8% to 20%, wet basis and a size of minus 1.3 cm with oxygen as the gasifying agent. A summary of the results from these tests is given in Table 5-6. This process yielded a gas having a lower H_2/CO ratio and a higher CO/CO_2 ratio.

Omnifuel has reported that the capital cost of the demonstration gasifier, including feeder, gasifier, and cyclones for primary removal of particulate matter will be $6 to $7 million.

(ii) Wright-Malta Corporation

The Wright-Malta Corporation has developed a catalysed steam gasification process that exposes biomass to 2,070 kPa steam at temperatures gradually increased to around 650°C. The biomass moves concurrently with the steam and evolved gases through an externally heated kiln.

Near 90% of the fuel value and 95% of the mass feed can be converted to gas under optimum conditons, about 2,070 kPa and 650°C. The

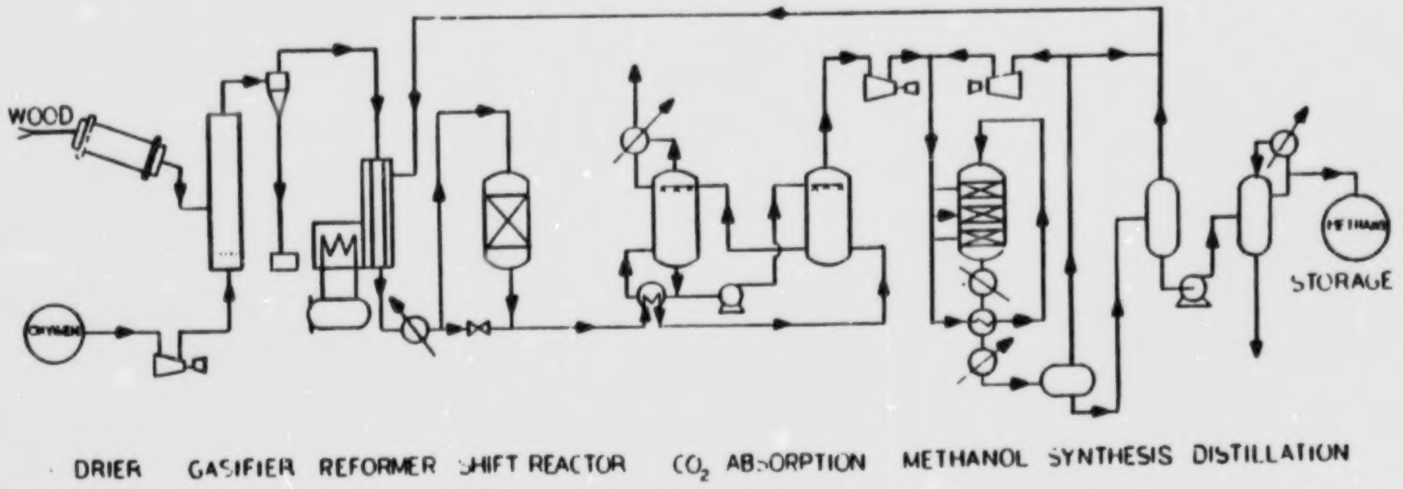

WOOD
OXYGEN
METHANOL
STORAGE
DRIER
GASIFIER
REFORMER
SHIFT REACTOR
CO_2 ABSORPTION
METHANOL SYNTHESIS
DISTILLATION

FIGURE 5-2 OMNIFUEL METHANOL PROCESS FLOWSHEET

TABLE 5-5

PREDICTED COMPOSITION OF SYNTHESIS GAS FROM AN OXYGEN-BLOWN OMNIFUEL GASIFIER OPERATING AT 1,830 kPa AND 870°C

Component	(Mol. %, Dry)
CO	45.2
H_2	21.4
CO_2	17.7
CH_4	9.8
C_xH_y	4.8
Tars & Oils	0.2
N_2	0.9
H_2/CO	0.47
CO/CO_2	2.55

TABLE 5-6

SUMMARY OF RESULTS FROM INCO TESTS OF AN OXYGEN-BLOWN FLUIDIZED-BED GASIFIER

Feedstock		Hammermilled Poplar Wood
Specific Feed Rate, t/m^2.h — 12% H_2O		3.25
Fluid-Bed Temperature, °C		850 - 900
Oxygen Requirement, kg/kg Wood (dry)		0.3
Steam Requirement, kg/kg Wood (dry)		0.025
Space Velocity, Actual m/sec		4 - 5
Dusting Rate, %		7.5
Reactor Gas Produced, std m^3 (dry)/kg Wood (dry)		1.27
Analysis of Reactor Gas (dry basis), Vol. % (Figures in the parenthesis give normal ranges of concentration)	CH_4	12.4 (10 - 15)
	CH_x(a)	3.2 (2.5 - 4)
	CO	48.2 (40 - 50)
	CO_2	15.2 (10 - 20)
	H_2	17.8 (10 - 20)
	O_2	0.7 (0 - 2)
	N_2	2.5 (1 - 5)
H_2/CO		0.37
CO/CO_2		3.17
Higher Heating Value of Gas (dry) kJ/m^3, 15°C, 101 kPa		13,000
Gross Thermal Efficiency(b)		90%
Heat Required for Drying		17.5%
Heat Required for Oxygen Production(c)		9%
Net Thermal Efficiency (b,d)		63.5%

(a) Consists of 2% C_2H_4, 0.5% C_3H_6, 0.05% C_3H_8, 0.25% C_4H_8 and 0.4% C_5H_{12}.

(b) Assuming recycling of residuals and waste heat recovery in boiler.

(c) Based on 440 kWh/t O_2 at an electrical power generation efficiency of 28.5%.

(d) Does not account for energy required for operating the plant mechanical and electrical equipment.

Source: Inco Metals Company

pyrolytic tars and oils are completely cracked to fixed gases so that the gas evolved from processing wood at 50% moisture content consists of CH_4 - 29.5%, C_2H_6 - 5.8%, CO - 8.5%, CO_2 - 39.8% and H_2 - 16.4% on a dry volume basis. This gas has a higher heating value of 18 MJ/m^3. Operation at zero gauge pressure reduces the methane content and results in a gas of about 13 MJ/m^3 heating value.

Heat for the kiln is supplied by steam and heat recovered from the produced fuel gas or external sources.

A pilot reactor was built and operated in 1981 (Figure 5-3). This unit used an internal auger to move solids through a 0.6 m diameter, 12 m long reactor. Due to solids flow problems, the best feed rate that could be achieved was 1.3 ODt/d, not the 3 ODt/d at 50% moisture content that was originally planned. Because of problems with solids flow through the reactor, a smaller test reactor was constructed that utilizes a central rotating shaft upon which are connected semicircular troughes designed to lift and tumble the wood feedstock. The company has proposed a modified reactor that would utilize this rotating aggitator in a gasifier tilted downward to promote material flow. Data from gasification of white pine at 45% moisture content with injected high-pressure steam in the original 6 t/d gasifier was previously presented in Table 5-2. These data were obtained at a pressure of 1,140 kPa and a temperature of 540°C (Wright-Malta Corp. 1982). Under these conditions, the higher heating value of the synthesis gas equalled 85% of the higher heating value of the dry wood feedstock.

The company claims that with heat recovery from the discharged synthesis gas to heat the reactor, no additional steam or heat is needed to promote the gasification process. From analysis of published experimental data, it is not possible to conclude with confidence whether this level of energy recuperation could be achieved

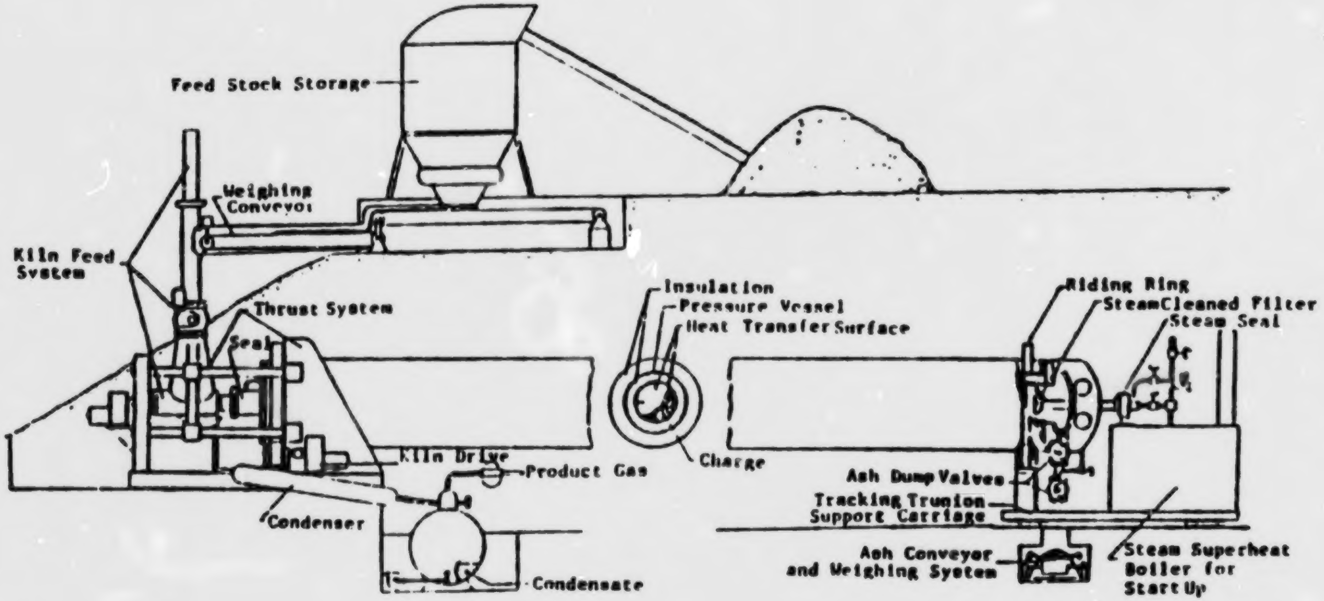

Feed Stock Storage
Weighing Conveyor
Kiln Feed System
Thrust System
Seal
Kiln Drive
Product Gas
Condenser
Condensate
Insulation
Pressure Vessel
Heat Transfer Surface
Charge
Riding Ring
SteamCleaned Filter
Steam Seal
Ash Dump Valves
Tracking Trunion Support Carriage
Ash Conveyor and Weighing System
Steam Superheat Boiler for Start Up

FIGURE 5-3 WRIGHT-MALTA GASIFICATION PROCESS

commercially. The reactions taking place in the reactor are both endothermic and exothermic, and no accurate value for the overall heat of reaction is available. It is claimed that the overall reaction is slightly exothermic, resulting in a process that does not need external heat addition. Since the experimental work conducted by Wright-Malta was done with steam addition and recovery of sensible heat from the synthesis gas, this same configuration is expected to be needed for any near-term use of this process for methanol synthesis.

Calculations conducted for this study using published data for operating conditions and gas composition indicate that heat/steam energy equal to 8% of the heating value of the wood is needed when the synthesis gas is cooled to 250°C by exchanging heat with the reactor. Lower gas temperatures may present problems because of condensation of tars and oils. Unconverted char and a wood ash and catalyst mixture are discharged from the gasifier and must be processed to recover the catalyst and prepare the char for use as a fuel or for recycle to the gasifier. The heating vlaue of the char is equal to about 7% of the heating value of the wood feed, or approximately the heat needed by the conversion process.

Several problems were encountered with the 6 t/d pilot gasifier, although all but the problem with obtaining satisfactory solids flow through the unit were of a relatively minor nature, and could be corrected by modification or replacement of components. Tests conducted in a reactor with an alternative paddle design were positive, and the company believes the next logical step in development will be construction of a pilot unit having a feedrate of near 200 t/d for wood chips or similar materials.

Na_2CO_3, $Ca(OH)_2$, and K_2CO_3 have been found to be effective catalysts for the gasification process. In early batch and continuous tests, the effect of catalyst concentration was investigated.

K_2CO_3 was found to be the most effective of the three catalysts tested over the range of concentrations considered. The effectiveness of the catalysts at decreasing char residue yields increased almost linearly with increasing catalyst concentration. Char yield from pure sawdust heated to 600°C and at a pressure of 2,000 kPa was reduced from 26% with no catalyst to 12% with 16% Na_2CO_3. Char yields when operating with K_2CO_3 catalyst solution are reported to have been 7% of carbon input from the wood.

(iii) Other Gasification Processes

As is evident from the previous discussion, there are a variety of gasification systems adaptable to production of synthesis gas from wood. There is good potential for adaption of previously-proven fixed-bed wood gasifiers such as the Davy design to current-day circumstances. With due consideration of the difficulty of handling wood fuels, there is also a good potential for adaption of demonstrated or proven coal gasification processes to wood feedstock. At the present time, only a few of the coal gasifier suppliers have systems available for wood feedstock, and none have an operating commercial unit producing synthesis gas. Both the Winkler high-temperature process and the Davy fixed-bed process are part of a demonstration program that has been funded by CESP of Sao Paulo, Brazil. This demonstration program has been halted pending a re-evaluation of the program objectives.

Many novel and improved wood gasification processes are being investigated. Most of these have been referenced previously. A process of particular interest for improved production of synthesis gas is the one under development at the Pacific Northwest Laboratory. This process utilizes a catalyzed fluidized-bed under pressure to gasify wood with steam; a process highly similar to the Wright-Malta process. A major thrust of the work at PNL is the development of catalysts to optimize yield and synthesis gas composition. The gasifier in this case is heated indirectly.

The direction of on-going research in synthesis gas production is to identify catalysts and operating conditions which are compatable with the requirements for methanol synthesis, and to minimize the yield of unconverted char and entrained particulate matter and tars and oils.

(b) Gas Cleanup and Upgrading

Various gas cleanup and gas upgrading processes are required to remove particulate matter, tars and oils, sulphur, and chloride contaminants and to adjust the hydrocarbon, hydrogen, and carbon monoxide concentrations to those compatable with methanol synthesis. The type and sequence of cleanup and modification processes depends on the quality of the crude synthesis gas leaving the gasifier, and to some degree, should be determined from energy and material balances of the whole methanol plant.

Table 5-7 lists synthesis gas contaminants and potential removal processes. For oxygen and steam gasification processes the major undersirable gas constituents are CO_2, tars and oils, particulate matter, and hydrocarbon gases. Sulphur and chloride compounds must be removed, even though present in only trace amounts, to protect the methanol synthesis catalysts. Table 5-8 summarizes the limits on contaminants to minimize catalysts degradation.

The first step to clean the crude synthesis gas is to remove particulate matter while the gas is hot and condensible hydrocarbons are in vapour form. For primary cleanup, cyclones are satisfactory for this purpose. If the gas is near atmospheric pressure, secondary cleanup is best handled with an electrostatic precipitator. If the gas is at elevated pressure, as is desired to reduce compression

TABLE 5-7

POTENTIAL PROCESS TECHNOLOGY FOR CLEANING AND UPGRADING SYNTHESIS GAS DERIVED FROM WOOD

Constituent	Typical Concentration	Potential Process
H_2S, CO_2	$H_2S \leq 500$ ppm $CO_2 \leq 20\%$	Acid gas scrubbing process
COS, CS_2	Trace	Selectively removed by acid gas process
NH_3, HCN	Trace	Water scrubbing and condensing
Char	$\leq 0.3\%$	Recycled as gasifier or utility fuels
Oils & Tar	Vary, depending on gasifier	Mist elimination or condenser separated; recycled in gasifier as combustible; residual treated in waste water
Particulate Matter	Low	Cyclone separators, hot fabric filters, wet scrubbers, electrostatic precipitators
Gaseous Hydrocarbon	Vary, depending on gasifier	Steam reforming, cryogenic separation

Source: Wan, et al 1979

TABLE 5-8

POTENTIAL METHANOL SYNTHESIS CATALYST CONTAMINATION LEVELS

Constituent	Contaimination Level and Potential
C_2H_4	potential poison @ > 3 ppm for Cu-Zn catalyst
C_2H_4, higher olefin	presently unknown, but possibly poisonous at higher concentration
CH_4, higher paraffin	inert
Sulfur (H_2S, COS, CS_2)	poison @ > 0.2 ppm for Cu catalyst poison @ > 10 ppm for Zn catalyst
Chlorides	poison @ > 0.2 ppm for Cu-Zn-Cr catalysts
NH_3, HCN	possible poison at modest concentration
Particulate	possible poison and affect catalyst life
Oil Mist	possible poison at modest amount

Source: Wan, et al 1979, Mittelhauser Corp.

energy requirements, then secondary cleanup of particulate matter must be combined with tar and oil removal to enable use of a pressurized wet scrubber.

The gas leaving the cleanup processes will be free of particulate matter, tars and oils, and mists, but will contain methane and other higher gaseous hydrocarbons, as well as high levels of CO_2 and trace amounts of sulphur compounds and chlorides. Since methane acts as an inert gas in the methanol synthesis reactor, a high carbon conversion efficiency may only be achieved if this methane and other paraffinic hydrocarbons are reformed to CO and H_2. The need for a reformer will depend on the paraffinic hydrocarbon concentration and the total energy requirement of the plant. If these combustible gases are not reformed, they may be purged from the methanol synthesis reactor and burned for fuel.

Steam reforming is conducted at 815 to 930°C over nickel-based catalyst. The reactor is arranged so that a mixture of steam and synthesis gas flow through an array of vertical tubes packed with catalyst and heated externally using a gaseous fuel obtained from a purge of the methanol synthesis reactor. The combustion gases exit the reformer at near 550°C and are then directed to a waste heat recovery boiler for generation of high-pressure steam. Heat is recovered from the hot reformed synthesis gas. This steam provides energy needed for the synthesis gas compressor and recirculator need for the methanol synthesis process.

To adjust the H_2/CO ratio, a water gas shift process may be used. This process reacts steam with carbon monoxide to yield carbon dioxide and hydrogen, thus increasing the H_2/CO ratio at the expense of higher carbon dioxide yields. Normally, carbon dioxide is present at a concentration in excess of that which is compatable with methanol synthesis, and a carbon dioxide removal process is required.

Carbon dioxide and hydrogen sulphide may be removed using many commercial acid gas removal processes. For synthesis gas derived from wood, the concentration of sulphur compounds will be less than about 300 ppm, while CO_2 levels will be between 15 to 20 volume % on a dry basis. At these gas concentrations, a hot carbonate absorption process of the Benfield or Catacarb designs would function effectively. In these processes, H_2S and CO_2 picked up in the absorbing column is released in the regenerator column by steam stripping and pressure reduction.

Following acid gas removal, the synthesis gas is suitable for compression and final cleaning to reduce the level of sulphur compounds and chlorides to levels acceptable to the methanol synthesis catalyst. Following these guard beds, synthesis proceeds.

(c) Methanol Synthesis

Methanol synthesis processes are marketed by several companies, the most commonly referenced one being Imperial Chemical Industries Ltd.

Operating conditions for typical low-pressure (5,050 to 10,100 kPa) processes are summarized in Table 5-9. A novel synthesis process is being developed by Chem Systems Inc. that utilizes a fluidized bed through which the synthesis gas and a combined heat transfer and fluidizing fluid flow. This process is to be tested at pilot-plant scale over the next year with an objective of completing most of the development work within three years. The Chem Systems process is not yet commercially available. Analyses reported by Sherwin and Frank show that the Chem Systems process requires less total horsepower and will have a lower capital cost than a multibed adiabatic quench process such as the ICI design of equivalent methanol output. The total recoverable chemical and sensible heat energy of the Chem Systems process is 97.9% compared to 86.3% for the multibed adiabatic quench process. The improved performance of this process makes

TABLE 5-9

TYPICAL LOW-PRESSURE METHANOL CATALYST AND SYNTHESIS PROCESSES

Vendor	Catalyst Type	Pressure (atm)	Temperature (°C)	Reactor Type	Cooling Mehtod
ICI	Cu-Zn-Al	50-100	220-290	Fixed, Multiple Bed	Gas Quench
Lurgi	Supported Cu	30-50	235-280	Tube in Shell	Steam Generation
Haldor Topsoe	Cu-Zn-Cr	50-100	220-350	Radial Flow	

Source: Reed (Ed)

it attractive emerging technology for reducing the cost of methanol produced from wood.

A comparison of the ICI, Lurgi, and Chem Systems processes is given in Table 5-10 showing the improved efficiency of the Chem Systems process and the impact of system pressure on efficiency for all processes. An operating pressure of near 5,100 kPa appears preferable to reduce horsepower requirements without reducing methanol yield. One penalty of lower pressure is the greater size of reactors and piping.

5.4 Base Case Plant for Methanol Production: 300 t/d Output

(a) Plant Design Basis

(i) Plant Size and Location

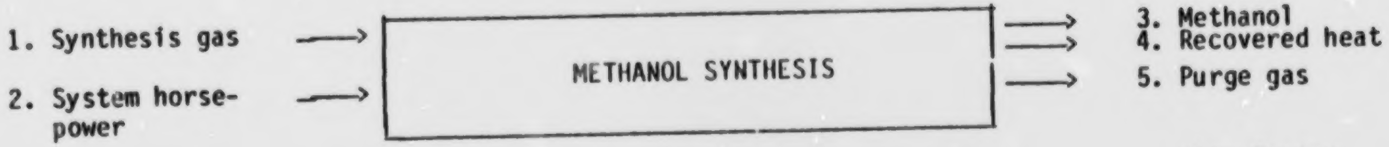
A base plant size was chosen that would consume somewhat less than the supply of wood residues available in the vicinity of Williams Lake or Kamloops. For design purposes, the upper limit on the supply of residues in one location was set at 270,000 ODt/y or 818 ODt/d, based on a 330-day year. With truck transportation of supplemental supplies, this wood supply could probably be increased to upwards of 370,000 ODt/y, although at a higher feedstock cost.

A methanol plant producing 300 t/d was selected for analysis. This plant has a wood requirement of about 724 ODt/d for both feedstock and fuel, leaving some unconsumed residues from the design upper limit. This 11% contingency in supply is intended to allow for the potential increased use of wood residues in the study area to generate mill energy requirements.

The plant is assumed to be located in the vicinity of Williams Lake or Kamloops, or any other location which offers a railroad link for

TABLE 5-10

COMPARISON OF METHANOL SYNTHESIS TECHNOLOGY


1. Synthesis gas
2. System horsepower
METHANOL SYNTHESIS
3. Methanol
4. Recovered heat
5. Purge gas

	ICI Multi-Bed Adiabatic Quench System		Lurgi Tube-Wall Isothermal Reactor System		Chem System Liquid Phase Reactor System	
Operating Pressure, kPa	5,170	10,300	5,170	10,300	5,170	10,300
Energy Balance GJ/t MeOH						
1. Synthesis gas	27.36	27.36	27.36	27.36	27.36	27.36
2. System horsepower requirements						
Feed compression[(a)]	0.93	2.88	---	2.88	---	2.00
Gas recycle	1.07	0.29	1.62	0.31	0.64	0.16
Oil circulation	---	---	---	---	0.31	0.14
TOTAL INPUT	29.35	30.53	28.97	30.56	28.31	29.64
3. Methanol	22.43	22.43	22.43	22.43	22.43	22.43
4. Recovery heat	1.34	1.36	2.73	2.79	2.99	3.00
5. Purge gas	1.15	1.16	1.15	1.17	1.15	1.38
TOTAL OUTPUT	24.92	24.95	26.31	26.39	26.57	26.81
Process efficiency, %	84.9	81.7	90.8	86.4	93.8	90.5

(a) Assume synthesis gas available at 3,445 kPa

Source: Wan, et al, 1979

transport of supplies and products, has a population in excess of about 10,000 people, and is near a natural gas pipeline. For a plant using wood feedstock only, natural gas is needed for startup.

No allowance has been made for site-specific costs such as land, special site development, etc., so that the plant costs would be applicable to any location. A more specific analysis would be needed to determine a detailed cost estimate for one location that includes all site factors.

(ii) Wood Feedstock Description

The feedstock was assumed to be a mixture of hogged and chipped wood and hogged bark received from mills without any other type of preparation. This feedstock would likely contain foreign material such as dirt, rock, and some tramp metal that would have to be removed during handling at the plant. The moisture content of the feedstock was taken to be nominally 45%, wet basis. Allowance was made for the presence of over-size materials that would have to be screened, then either disposed of or hogged and returned to the feed stream. A composition was assumed for the wood feedstock that was felt to be representative of a mixture of pine, hemlock, and Douglas Fir (Table 5-11).

(iii) Methanol Specifications

The minimum methanol content of the final product was taken to be 99.5%. The fuel-grade product will also contain acetone and aldehydes, as well as a small amount of water.

(iv) Gasifier

The gasifier chosen for this study is the unit under development by Wright-Malta that uses a catalyzed steam gasification process. The

TABLE 5-11

DESIGN WOOD COMPOSITION

Constituent	Wt %, Dry
Carbon	49.92
Hydrogen	5.94
Oxygen	42.79
Nitrogen	0.09
Sulphur	0.05
Ash	1.21
	100

gas composition and yield of gases and char are as given in Table 5-12. The gasifier operates at 540°C and 1,144 kPa using hogged and chipped residues with an internal rotating paddle affixed to a central shaft. The residence time of solids in the gasifier is about one hour. The gas composition was based on published experimental data obtained from tests using a 6 t/d continuous-flow gasifier. Operation at different temperatures and pressures and with a different type of feedstock will likely lead to production of a synthesis gas having a different composition and yield than that which was assumed. A more optimal gasification process will likely be achieved at a pressure near 2,000 kPa, rather than the 1,144 kPa used during the company's tests, based on results of earlier work done with batch reactors (Wright-Malta Corp.)

The Wright-Malta process was selected instead of an oxygen-blown gasification process because it can accept wet coarse wood residues, it does not require an oxygen plant, the methanol price predicted by Wan et al is lower, and the overall plant efficiency is higher. Because of the lack of commercial experience with either steam gasification and oxygen gasification, it is not possible to conclude with confidence whether either approach is better in terms of lower product cost. The methanol costs predicted by Wan et al for all gasification processes are within plus or minus $0.03 per litre, a negligibly small value considering the uncertainty in the estimates of capital and operating costs.

(v) Utilities

Electricity, water and natural gas for the plant are available at the plant battery limits. The plant electricity requirement is for equipment that can not be driven practically with steam; and for backup systems. The plant does not generate electricity for its own use, although this is technically feasible. Water supplied to the plant is used for potable water, boiler water make-up, and cooling water. Natural gas is needed for plant startup.

TABLE 5-12

WRIGHT-MALTA GASIFIER PERFORMANCE DATA

Biomass feed	45% moisture content
Gasification composition	
H_2	16.9
CO	3.0
CO_2	24.8
CH_4	13.3
C_2H_6	2.4
H_2O	39.6
Gas Yield	79.29 mol/kg dry wood
Gas molecular weight	22.07 g/mol
Char yield	0.07 kg/kg dry wood

(b) Selection and Description of Process Components

(i) Summary

The process configuration for a methanol plant using a Wright-Malta steam gasification process is presented in Figure 5-4.

Moist wood at nominally 45% moisture content already hogged is received at the plant gate and stored in a highly automated storage and reclamation area. Wood is screened and separated; over-size materials are hogged. This feedstock is split to flow to a high-pressure boiler for supply of steam at 4,200 kPa and 400°C to the plant.

Gas leaving the gasifier at pressure is cleaned to remove entrained particulate matter and tar and oil vapours. Heat is recovered from the crude synthesis gas by passing it over the exterior of the gasifier prior to the cleanup equipment.

At the existing gas pressure, paraffinic hydrocarbons, primarily methane, are reformed to CO and H_2. Some of the synthesis gas is used in the reformer as fuel to augment the purge-gas fuel stream.

Carbon dioxide and H_2S are removed in the acid gas removal step to adjust the ratio of hydrogen and carbon oxides. This synthesis makeup gas is then compressed to synthesis pressure (5,050 kPa) before passing to chloride and sulphur guard that reduce contaminants which poison the methanol catalyst.

The crude methanol product is subsequently distilled to the 99.5% purity level and shipped to storage.

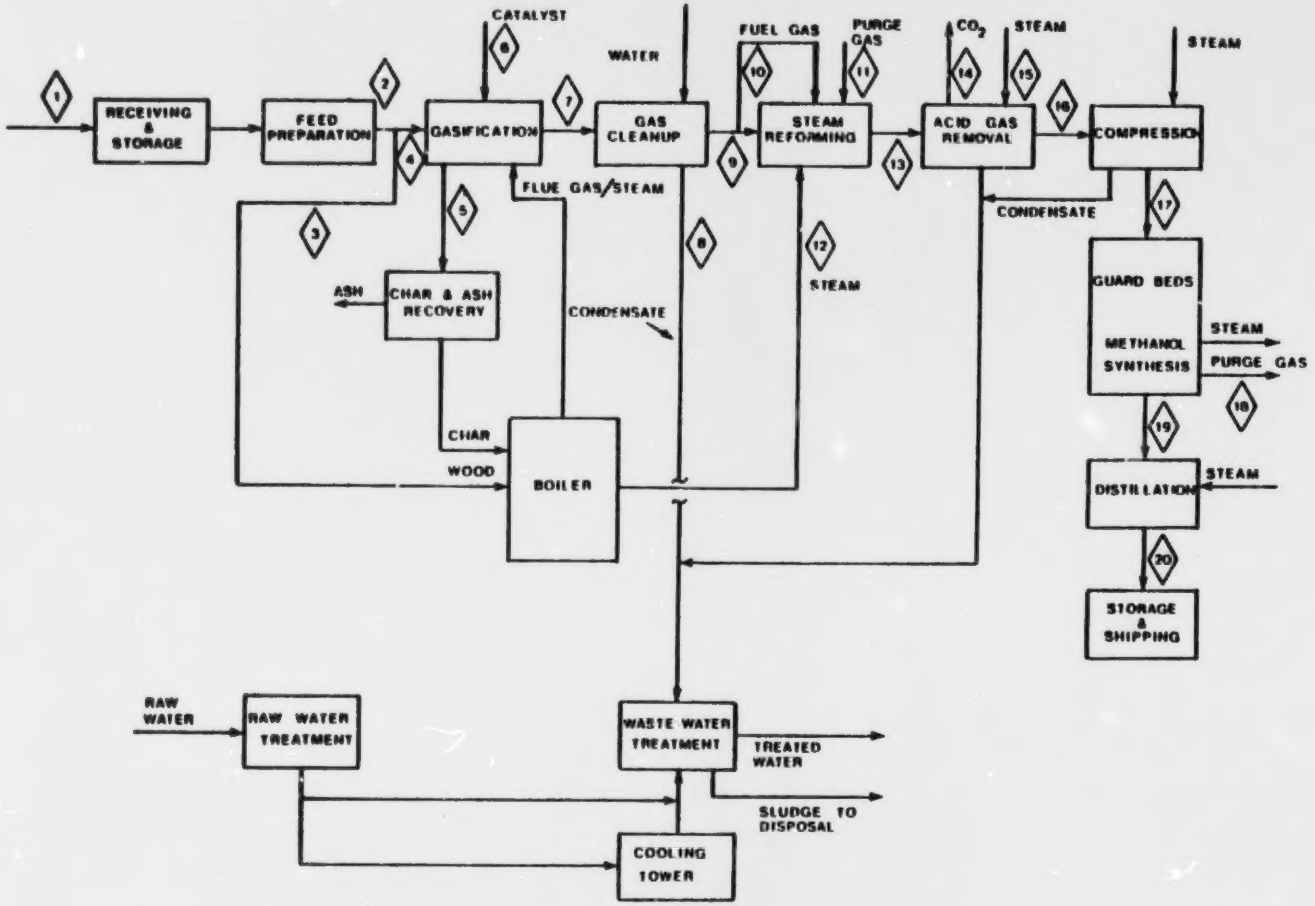

1
RECEIVING & STORAGE
FEED PREPARATION
2
3
4
CATALYST
6
GASIFICATION
5
ASH
CHAR & ASH RECOVERY
CHAR
WOOD
BOILER
FLUE GAS/STEAM
7
WATER
GAS CLEANUP
CONDENSATE
8
9
FUEL GAS
10
PURGE GAS
11
STEAM REFORMING
12
STEAM
13
CO2
14
STEAM
15
ACID GAS REMOVAL
16
CONDENSATE
STEAM
COMPRESSION
17
GUARD BEDS
METHANOL SYNTHESIS
STEAM
PURGE GAS
18
19
STEAM
DISTILLATION
20
STORAGE & SHIPPING
RAW WATER
RAW WATER TREATMENT
WASTE WATER TREATMENT
TREATED WATER
SLUDGE TO DISPOSAL
COOLING TOWER

FIGURE 5-4 METHANOL SYSTEM FOR WRIGHT MALTA GASIFIER

(ii) Feedstock Storage and Handling

Wood is received in trucks which pass over a weigh scale upon entering the plant and then are unloaded using two hydraulic inclining truck dumpers. Coarse screening is done at this point to remove materials too large to be handled by the stacker/reclaimer. This material is checked for metals, hogged, and then recombined with the primary feedstock stream going to storage.

Reclamation of the feedstock is done using an underpile reclaimer fed by mobile equipment. The storage area allows for a 60-day inventory of hogged moist residues.

Reclaimed feedstock is conveyed to screens and metal detectors for removal of foreign and over-size materials. Foreign materials go to disposal, while over-size residues are recycled. The feed stream is split, sending the required feedrate to maintain the boiler. This fuel is used without drying, although a dryer could be included to increase the boiler output.

(iii) Gasification and Gas Cleanup

Wood is fed to two gasifiers each sized to 350 ODt/d input. Further development work is needed to develop the gasifiers for this capacity and to identify the best feeder for the gasifier from several promising candidates, including a lock hopper system and a reciprocating piston/seal valve combination.

The synthesis gas exiting the reactor is passed back over the exterior of the gasifier to recover some of the sensible heat. Depending on the overall heat of reaction of the wood and the heat losses from the exterior of the gasifier, either some steam may have to be injected with the wood, or supplemental heating may be needed to achieve the desired operating conditions. The heat requirement under the worst conditions is small compared to that of some other plant process equipment.

The synthesis gas reportedly contains very little particulate matter and tar vapours. It has been assumed that some of these contaminants are present, though at levels low enough to not present problems for their removal.

By transfer of heat to the reactor, the synthesis gas may be cooled to about 250°C. Lower temperatures were avoided to prevent deposition of tars.

The partially-cooled synthesis gas leaving the gasifier passes to a heat exchanger for further heat recovery, then to a spray scrubber and demister to remove particulate matter and condensible hydrocarbons. The synthesis gas exits the gas cleanup equipment at about 1,144 kPa and 38°C.

After gas cleanup, the synthesis gas contains trace amounts of fixed contaminant gases such as H_2S and other sulphur compounds and chlorides.

(iv) Synthesis Gas Reforming

The synthesis gas leaving the gas cleanup system contains 25.83 mol % methane and ethane. These gases are catalytically reformed to CO and H_2 with steam to yield a gas composed primarily of H_2, CO, and CO_2 in a ratio of 2.58:1:0.81.

Steam is added with the synthesis gas at a ratio of 1.08 mole steam to 1 mole synthesis gas.

Heat is supplied to the reformer by combustion of a mixture of purge gas from the methanol synthesis reactor and a portion of the synthesis gas leaving the gas cleanup system. About 28% of the clean synthesis gas stream is diverted for this use. The reformer operates at 1,144 kPa and about 815°C and uses a nickel-based catalyst.

Hot combustion exhaust gases are passed from the reformer to a waste heat boiler to generate steam at 4,130 kPa and 400°C. Heat is also recovered from the hot synthesis gas, reducing its temperature to 93°C before exit to the acid gas removal train. The gas pressure at exit is 865 kPa.

(v) Acid Gas Removal

The reformed synthesis gas contains an undesirable concentration of CO_2, giving a $H_2:CO:CO_2$ ratio of 2.58:1:.81 and a $H_2/CO + 1.5\ CO_2$ ratio of 1.165. This latter ratio must be raised to near 2.0 to achieve effective synthesis.

A Benfield hot potassium carbonate acid gas removal system was chosen for CO_2 removal. Some of the H_2S which may have been generated from small amounts of sulphur present in the wood will also be removed in this process step. H_2S levels are expected to decrease in the same proportion as for CO_2. The maximum removal of H_2S for this hot carbonate process is 90% to 98%.

The absorber and regenerator columns operate at about 110°C. The absorber column operates at a pressure of 865 kPa, while the regenerator operates at slightly above atmospheric pressure.

The absorbed CO_2 and H_2S is striped from the hot carbonate solution by dropping the pressure to near atmospheric and passing the solution downwards through a rising flow of steam. The regenerated solution is recycled to the absorber column.

At the exit of the absorber column, the synthesis gas has a $H_2/(CO + 1.5CO_2)$ ratio of 1.8 and has a H_2/CO ratio of 2.58:1. This gas also contains about 16.6 mol % water vapour.

(vi) Compression

The makeup synthesis gas leaving the acid gas removal process is at a pressure of 865 kPa and must be compressed to methanol synthesis pressure (5,050 kPa). Also, the water content of the gas must be reduced.

Steam-driven compressors are used to compress the gas to 5,050 kPa. The makeup gas is cooled during compression to reduce the water vapour content to 0.13 mol %.

(vii) Methanol Synthesis and Distillation

The low-pressure methanol synthesis process developed by Imperial Chemical Industries (ICI), of the United Kingdom, and marketed under license in North America by the Davy McKee Corp. was chosen for this study. This process conducts methanol synthesis over a proprietary copper-based catalyst at a pressure of 5,050 to 10,100 kPa and a temperature of 210 to 290 C (Pinto and Rogerson).

For synthesis gas derived by gasification, Pinto and Rogerson have determined that there is no advantage in increasing synthesis pressure above 5,050 kPa, since carbon conversion efficiency increases from 97% to 99% as pressure increases from 5,050 to 10,100 kPa and, for this reason, the synthesis pressure was not set at 5,050 kPa. Over this pressure range, total power to circulate and compress the makeup gas increases from 12,000 kW to 15,000 kW, an increase of 25%. Pinto and Rogerson also suggest that for a natural-gas-fed methanol plant with gas at $1.90/GJ, the optimum synthesis pressure is from 7,340 kPa to 8,715 kPa. Lower energy costs make higher pressures more attractive.

To protect the sensitive copper-based catalyst, the synthesis reactor is preceded by two guard beds to reduce the levels of sulphur compounds and chlorides to below levels that would reduce the effectiveness of the synthesis catalyst. The makeup gas enters the synthesis loop at 38°C.

Recycled gas is combined with the synthesis gas downstream of the guard beds, and this mixture is then sent to the methanol synthesis reactor. The converter effluent is sent to a crude methanol convertor; a knock-out drum type unit. The gas flow from this knock-out drum is split into two flows. The bulk of the gas is recycled to be recombined with the incoming synthesis gas, while about 8% is purged to control the level of inerts going through the synthesis reactor. This purge is used in the reformer as fuel.

The liquid recovered in the knock-out drum contains methanol, water, and dissolved gases and chemicals formed by side reactions. This crude methanol is let down to 670 kPa in a flash drum to remove dissolved gases picked up at synthesis pressure. This gas is used as a fuel gas, while the remaining crude methanol, containing dimethyl ether and ethyl alcohol, water and methanol, is sent to the distillation process.

A single distillation column is used. The crude methanol is mixed with an aqueous solution of sodium hydroxide to neutralize any organic acids to suppress corrosion. This stream is distilled. Overheads from the column and fuel oil taken off as a sidestream near the bottom of the column are used as fuels in the plant. The refined methanol is taken off near the top of the column, cooled, and sent to storage.

(viii) Balance of Plant

The balance of the plant consists of:

- waste water treatment;
- raw water treatment and cooling tower;
- storage and shipping;
- utility distribution;
- boiler and feedwater system.

All liquid waste water streams are treated in a biological treatment system before discharge. The treated streams include gas cleanup, acid gas condensate, compression condensate, waste water from distillation, and boiler and cooling tower blowdowns.

Raw water is delivered from outside the battery limits and kept in a storage area. This water is the supply for the cooling tower, the makeup for the boiler, and the potable water system. The potable water is passed through activated carbon filters and then on to storage.

The boiler supplies high-pressure steam for the plant that supplements process-generated steam. The boiler generates 22,000 kg/h of steam at 4,240 kPa and 400°C from wet wood and from char discharged from the gasifier. The boiler is also equipped with a gas burner for firing with process-derived fuel gases. Wood is the primary fuel. The boiler is a packaged design and is complete with boiler feed water preparation, fuel handling, air heater, economizer, fans, and control system.

(c) Material and Energy Balances

A process flowsheet for the Wright-Malta gasification and methanol synthesis process is given previously in Figure 5-4. Flows by the

the stream numbers in this figure are summarized in Appendix A in Table A-1.

Since all mechanical power needed for major process compressors is generated by steam, the plant thermal efficiency has been defined as:

$$\text{Efficiency, \%} = 100 \times \frac{\text{Higher Heating Value of Methanol}}{\text{Higher Heating Value of Wood}}$$

Based on a higher heating value of wood of 19,800 kJ/kg and a higher heating value of liquid methanol of 22,737 kJ/kg, overall plant thermal efficiency is 47.5%.

Wan et al have calculated the electrical requirements of a plant in which steam was used for major prime movers. The electrical requirements for this 454 t/d methanol plant were 16 million kWh per year. Scaling this to 300 t/d methanol using an exponent of 0.86 gives 11.2 million kWh per year, or an average demand of 1,415 kW. Including this energy at 3,600 kJ/kWh gives an overall plant efficiency of 47.1%.

(d) Capital and Operating Costs

Direct and indirect capital costs were determined for the base case plant using several sources, including studies of wood-to-methanol plants conducted by Wan, et al (1979, 1981) and Mudge, et al, as well as from in-house cost data.

Capital costs for a 300 t/d methanol plant are summarized in Table 5-13. A contingency of 15%, in the upper area of the 10% to 20% range that is typical, was used to allow for the uncertainties which exist in this conversion technology and the added costs that would be incurred from redesign of some process components of the

Table 5-13

CAPITAL COSTS FOR A 300 t/d

WRIGHT-MALTA STEAM GASIFICATION METHANOL PLANT

Total Wood Feed (ODt/d)	724
Wood to Gasifier (ODt/d)	600
Wood to Boiler (ODt/d	124
Methanol Production (t/d)	300

DIRECT AND INDIRECT CAPITAL COSTS:	($1,000)
Wood Storage and Handling	7,120
Gasification and Gas Cleanup	20,390
Gas Compression	2,640
Acid Gas Removal	2,520
Steam Reforming	2,270
Methanol Synthesis and Purification	13,120
Boiler and Feed Water System	2,170
Raw Water Treatment and Cooling Tower	1,160
Waste Water Treatment	3,670
Utility Distribution	880
Building and Site Development	2,150
Storage and Shipping	1,060
SUBTOTAL CAPITAL COSTS	59,150
Professional Services (10%)	5,920
Contingency (15%)	8,870
TOTAL INSTALLED COST (TIC)	73,940
Startup Costs 5% TIC	3,700
Working Capital 2.5% TIC	1,850
	79,490

plant, and the fact that the cost estimates were not based on any detailed plant drawings and therefore do not account for some costs for interconnecting process units.

The factors used for startup cost and working capital are typical industrial values for new technology.

Operating costs for a 300 t/d methanol plant are summarized in Table 5-14. Utility requirements are based on operating requirements. The electricity cost is based on a monthly maximum demand 25% above the average demand was calculated according to a B.C. Hydro Rate Schedule 1201. Maintenance cost was set at 4.5% of the total installed cost of the plant, split 60% to labour; 40% to supplies.

5.5 Capital and Operating Costs for a 600 t/d Methanol Plant

Capital costs for a 600 t/d methanol plant were scaled up from the costs for a 300 t/d plant using average industrial exponents given by Guthrie and Mudge, et al. Wood storage and handling capital cost was scaled with an exponent of 0.9 while all remaining components, except the boiler and feedwater system, were scaled with an exponent of 0.6. The boiler system was scaled using an exponent of 0.7. A summary of the costs is given in Table 5-15.

Operating costs for the 600 t/d methanol plant are given in Table 5-16. These costs were estimated using the same unit prices as for the 300 t/d methanol plant with appropriate increases in utility, labour, and all supplies.

The capital costs determined for the 300 and 600 t/d methanol plants are very similar to a best estimate of the plant costs derived from averaging results of other studies (Figure 5-5). For this plot, costs were brough to mid 1982, using the CE plant index. These data

Table 5-14

OPERATING COSTS FOR A 300 t/d

WRIGHT-MALTA STEAM GASIFICATION METHANOL PLANT

	Annual Quantity	Unit Price ($/Unit)		Annual Cost ($1,000)
Utilities				
Electricity	11.2×10^6 kWh	0.025/kWh		280
Water	1.07×10^6 kL	0.11/kl		118
			S/T	398
Labour				
Operating	60 men @ 2,080 h	13.50/h		1,685
Maintenance	2.7% TIC			2,000
Supervision	20% op. & maint. labour			737
			S/T	4,422
Catalysts and Chemicals				
Gasifier Catalyst	1,386 t	132/t		183
Chloride Guard Catalyst	31.2 m^3	6,300/m^3		197
Sulphur Guard Catalyst	23.6 m^3	3,126/m^3		74
Methanol Catalyst	confidential			142
Reformer Catalyst	3.5 m^3	9,793/m^3		34
			S/T	630
Supplies				
Maintenance	1.8% TIC			1,330
Operating	30% of op. labour			506
			S/T	1,836
Administration and General Overhead 70% Total Labour				3,095
Taxes and Insurance 2.5% of TIC				1,849
TOTAL OPERATING COSTS				12,230

Table 5-15

CAPITAL COSTS FOR A 600 t/d
WRIGHT-MALTA STEAM GASIFICATION METHANOL PLANT

Total Wood Feed (ODt/d)	1,448
Wood to Gasifier (ODt/d)	1,200
Wood to Boiler (ODt/d	248
Methanol Production (t/d)	600

DIRECT AND INDIRECT CAPITAL COSTS:	($1,000)
Wood Storage and Handling	13,280
Gasification and Gas Cleanup	30,910
Gas Compression	3,640
Acid Gas Removal	3,810
Steam Reforming	3,430
Methanol Synthesis and Purification	19,890
Boiler and Feed Water System	3,530
Raw Water Treatment and Cooling Tower	1,980
Waste Water Treatment	5,560
Utility Distribution	1,330
Building and Site Development	3,250
Storage and Shipping	1,640
SUBTOTAL CAPITAL COSTS	92,250
Professional Services (10%)	9,225
Contingency (15%)	13,840
TOTAL INSTALLED COST	115,315
Startup Costs 5% TIC	5,770
Working Capital 2.5% TIC	2,880
	123,965

Table 5-16

OPERATING COSTS FOR A 600 t/d
WRIGHT-MALTA STEAM GASIFICATION METHANOL PLANT

	Annual Quantity	Unit Price ($/Unit)	Annual Cost ($1,000)	
Utilities				
Electricity	20.3×10^6 kWh	0.026/kWh		528
Water	2.14×10^6 kl	0.11/kl		235
			S/T	763
Labour				
Operating	96 men @ 2,080 h	13.50/h		2,696
Maintenance	2.7% TIC			3,114
Supervision	20% op. & maint. labour			1,162
			S/T	6,972
Catalysts and Chemicals				
Gasifier Catalyst	2,772 t	132/t		366
Chloride Guard Catalyst	62.4 m^3	6,300/m^3		393
Sulphur Guard Catalyst	47.2 m^3	3,126/m^3		148
Methanol Catalyst	confidential			284
Reformer Catalyst	7 m^3	9,793/m^3		69
			S/T	1,260
Supplies				
Maintenance	1.8% TIC			2,076
Operating	30% of op. labour			809
			S/T	2,885
Administration and General Overhead 70% Total Labour				4,880
Taxes and Insurance 2.5% of TIC				2,883
TOTAL OPERATING COSTS				19,643

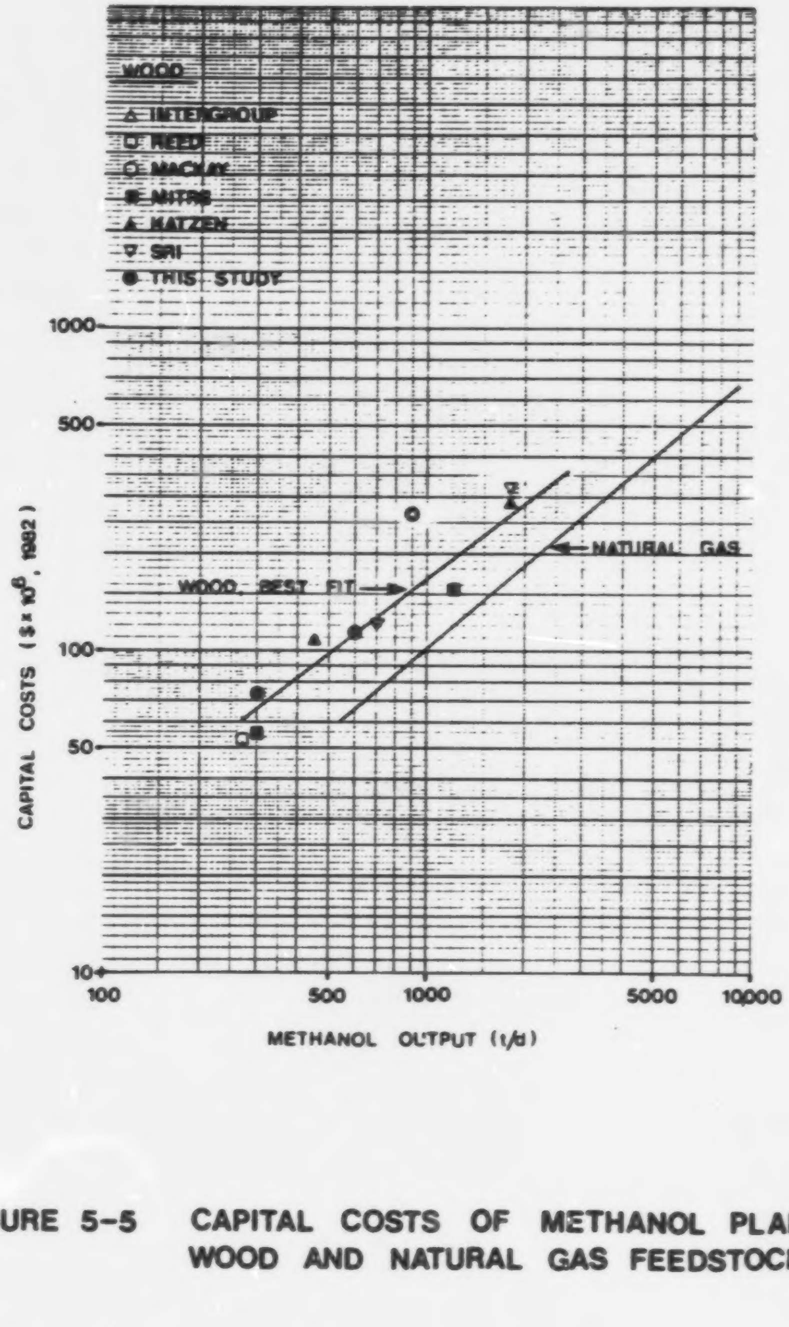


FIGURE 5-5 CAPITAL COSTS OF METHANOL PLANTS FOR WOOD AND NATURAL GAS FEEDSTOCKS

indicate that capital costs increase in proportion to the ratio of capacities to the 0.6 to 0.8 power. The capital costs of methanol plants using natural gas feedstock are clearly lower than those for wood feedstocks. Few plants using natural gas feedstocks are installed for productions less than 1,000 t/d.

5.6 Hybrid Methane and Wood Feedstock Methanol Plant

(a) Process Description

Synthesis gas produced by wood gasification has insufficient hydrogen for stoichiometric conversion of carbon oxides to methanol. For the Wright-Malta process, gasification of one oven-dry tonne of wood yields 61.92 kmol of reformed gas as carbon monoxide, carbon dioxide, and hydrogen. This value excludes gas needed as fuel for the reformer, as well as minor gases, primarily water vapour, that exit the reformer but are not involved in methanol synthesis.

Consider 100 moles of reformed gas consisting of carbon monoxide, carbon dioxide, and hydrogen. For stoichiometric conversion, carbon oxides in the 100 moles of synthesis gas consisting of:

$$22.78\ CO + 18.44\ CO_2 + 58.77\ H_2$$

the following reactions must occur:

$$\begin{array}{l}
22.78\ CO + 45.56\ H_2 \longrightarrow 22.78\ CH_3OH \\
18.44\ CO_2 + 55.32\ H_2 \longrightarrow 18.44\ CH_3OH + 18.44\ H_2O \\
\hline
22.78\ CO_2 + 18.44\ CO_2 + 100.88\ H_2 \longrightarrow 41.22\ CH_3OH + 18.44\ H_2O
\end{array}$$

The hydrogen requirement for these reactions exceeds that present in the synthesis gas by 42.11 moles. This deficit may be made up by utilizing the excess hydrogen present in reformed natural gas.

Reformation of natural gas to yield 100 moles of synthesis gas under ideal conditions proceeds according to the reaction:

$$23.07\ CH_4 + 30.76\ H_2O \longrightarrow 15.38\ CO + 76.92\ H_2 + 7.69\ CO_2$$

This gas may be converted to methanol by the following reaction:

$$15.38\ CO + 76.92\ H_2 + 7.69\ CO_2 \longrightarrow 23.07\ CH_3OH + 23.08\ H_2 + 7.69\ H_2O$$

Mixing this gas with synthesis gas in a proportion to maximize methanol yield give the gas mixture:

$$\begin{array}{l} \frac{42.11}{23.08}\ (15.38\ CO + 76.92\ H_2 + 7.69\ CO_2) \\ \quad +\ \ 22.78\ CO + 58.77\ H_2 + 18.44\ CO_2 \\ \hline 50.84\ CO + 199.11\ H_2 + 32.47\ CO_2 \end{array}$$

Conversion of this gas to methanol proceeds as follows:

$$50.84\ CO + 199.11\ H_2 + 32.47\ CO_2 \longrightarrow 83.31\ CH_3OH + 32.47\ H_2O$$

To achieve this yield, 1.825 moles of reformed natural gas is mixed with 1 mole of wood-derived synthesis gas.

For the actual yield of reformed synthesis gas from wood, allowing for the synthesis gas used for reformer fuel, the feedstock methane required to supply the required hydrogen under ideal conditions is given by the relationship:

$$\underset{\text{to gasifier}}{0.603\ \text{OD kg wood}} + 0.373\ m^3\ @\ 15°C\ CH_4 \longrightarrow 1\ \text{kg}\ CH_3OH$$

An allowance may be made for the methane required for fuel by using data for conventional methanol plants using natural gas feedstock. Uhde GmbH states that the natural gas fuel requirement for a methanol plant is 4.45% of the feedstock requirement. Allowing for this natural gas fuel requirement and, as before, the portion of the wood-derived synthesis gas also used as fuel in the base case plant analysis, the relationship for methanol yield becomes:

$$\underset{\text{to gasifier}}{0.603\ \text{OD kg wood}} + \underset{\text{feedstock}}{0.373\ \text{m}^3\ @\ 15^\circ\text{C CH}_4} + \underset{\text{fuel}}{0.020\ \text{m}^3\ @\ 15^\circ\text{C CH}_4} \longrightarrow 1\ \text{kg CH}_3\text{OH}$$

A summary of the wood and methane requirements for a yield of 1 kg of methanol and the carbon conversion efficiency of these processes is given in Table 5-17. The methane requirements are likely an underestimate since no allowance has been made for hydrogen from natural gas reformation that, though normally used for fuel, would now be consumed for methanol production, and no allowance has been made for non-stoichiometric conversion of feedstock methane. This data shows the vast differences in carbon conversion efficiencies for the various feedstocks. Of most significance is that if the same quantities of wood and methanol used in the hybrid example were processed separately, 0.8 kg of methanol would be produced instead of the actual yield of 1 kg, a consequence of the improved use of the carbon dioxide produced by wood gasification.

(b) Capital and Operating Costs

Two concepts were considered for a hybrid wood/methane feedstock plant. The optimistic case assumed that the synthesis gas from wood gasification was mixed directly with natural gas after gas cleanup, then this gas was reformed. The acid gas removal step in this case is no longer needed. The pessimistic case assumed that the wood-to-methanol and natural gas-to-methanol trains operate independently with a transfer of hydrogen from the natural gas-fed to the wood-fed trains. Both cases assumed a wood gasification rate equal to that used for the base case plant.

Capital and operating costs were developed for each case and are expected to cover the possible cost range.

Table 5-17

WOOD AND METHANE REQUIREMENTS TO YIELD 1 kg OF METHANOL BY VARIOUS METHANOL CONVERSION PROCESSES

	Feed Quantity		
Feedstock	Wood Feedstock (ODkg)	Methane Feedstock and Fuel (m3 @ 15°C)	Carbon Conversion Efficiency (%)
Wood (Wright-Malta process)	2.0[a]	---	38
	2.4[b]	---	31
Wood and methane gases mixed upstream of reformer	0.603[a]	0.393[c]	76
	0.728[b]	0.393[c]	68
Methane	---	0.78[c]	95

---

[a] Excludes wood used for boiler fuel.

[b] Includes wood used for boiler fuel.

[c] Assumes complete conversion of feedstock methane to methanol. In practice, total methane required will exceed these values by 5% to 15% due to conversion inefficiency.

Capital and operating costs for the case of a combined synthesis gas are given in Tables 5-18 and 5-19.

The capital cost of a plant consisting of two trains, one with wood feedstock, the other with natural gas feedstock, was determined from data presented previously for the 300 t/d wood-fed plant and data given by Rock for a natural gas-fed plant. The total installed cost of this plant is:

Wood-fed train	- $73.9 X 10^6
Natural gas-fed train	- $65 X 10^6
	$138.9 X 10^6

The total methanol production from this plant is equal to that for the previous case.

The operating costs for this plant are given in Table 5-20.

5.7 Impact of Future Technological Improvements on Methanol Production From Wood

Technology for producing a synthesis gas from wood that is suitable for subsequent conversion to methanol is presently under development by numerous government laboratories and companies, primarily in the United States, Canada, Brazil, Sweden, and France. Existing processes are at varying levels of development, the most advanced being at a pilot-scale level.

Technology for cleaning and modification of a synthesis gas derived from wood and for conversion of this gas to fuel or chemical-grade methanol is commercially available and well proven in comparable applications, such as chemical plants using coal, natural gas, and petroleum feedstocks. At present, there are not any methanol plants operating with a wood feedstock.

Table 5-18

CAPITAL COSTS FOR A 990 t/d Hybrid
WRIGHT-MALTA STEAM GASIFICATION METHANOL PLANT

Total Wood Feed (ODt/d)	724
Wood to Gasifier (ODt/d)	600
Wood to Boiler (ODt/d	124
Natural Gas - Feed (m^3/d)	369,780
- Fuel (m^3/d)	20,141
Methanol Production (t/d)	990

DIRECT AND INDIRECT CAPITAL COSTS:	($1,000)
Wood Storage and Handling	7,280
Gasification and Gas Cleanup	20,390
Gas Compression	5,040
Steam Reforming	4,220
Methanol Synthesis and Purification	26,900
Boiler and Feed Water System	4,490
Raw Water Treatment and Cooling Tower	2,670
Waste Water Treatment	3,820
Utility Distribution	1,800
Building and Site Development	4,400
Storage and Shipping	2,170
SUBTOTAL CAPITAL COSTS	83,020
Professional Services (10%)	8,300
Contingency (20%)	16,600
TOTAL INSTALLED COST (TIC)	107,920
Startup Costs 5% TIC	5,396
Working Capital 2.5% TIC	2,698
	116,014

Table 5-19

OPERATING COSTS FOR A 990 t/d HYBRID WRIGHT-MALTA STEAM GASIFICATION METHANOL PLANT

	Annual Quantity	Unit Price ($/Unit)		Annual Cost ($1,000)
Utilities				
Natural Gas	0.23 X 10^6 GJ	3.26/GJ		745
Electricity	31.3 X 10^6 kWh	0.024/kWh		752
Water	3.54 X 10^6 kL	0.11/kl		389
			S/T	1,886
Labour				
Operating	96 men @ 2,080 h	13.50/h		2,696
Maintenance	2.7% TIC			2,910
Supervision	20% op. & maint. labour			1,120
			S/T	6,726
Catalysts and Chemicals				
Gasifier Catalyst	1,386 t	132/t		183
Chloride Guard Catalyst	103 m^3	6,300/m^3		649
Sulphur Guard Catalyst	78 m^3	3,126/m^3		244
Methanol Catalyst	confidential			470
Reformer Catalyst	12 m^3	9,793/m^3		118
			S/T	1,664
Supplies				
Maintenance	1.8% TIC			1,940
Operating	30% of op. labour			809
			S/T	2,749
Administration and General Overhead 70% Total Labour				4,708
Taxes and Insurance 2.5% of TIC				2,698
TOTAL OPERATING COSTS				20,431

Table 5-20

OPERATING COSTS FOR A 990 t/d HYBRID WRIGHT-MALTA STEAM GASIFICATION METHANOL PLANT WITH SEPARATE SYNTHESIS PROCESSES

	Annual Quantity	Unit Price ($/Unit)		Annual Cost ($1,000)
Utilities				
Natural Gas	0.23 X 10^6 GJ	3.26/GJ		745
Electricity	31.3 X 10^6 kWh	0.024/kWh		752
Water	3.54 X 10^6 kL	0.11/kl		389
			S/T	1,886
Labour				
Operating	96 men @ 2,080 h	13.50/h		2,696
Maintenance	2.7% TIC			3,750
Supervision	20% op. & maint. labour			1,289
			S/T	7,735
Catalysts and Chemicals				
Gasifier Catalyst	1,386 t	132/t		183
Chloride Guard Catalyst	103 m^3	6,300/m^3		649
Sulphur Guard Catalyst	78 m^3	3,126/m^3		244
Methanol Catalyst	confidential			470
Reformer Catalyst	12 m^3	9,793/m^3		118
			S/T	1,664
Supplies				
Maintenance	1.8% TIC			1,664
Operating	30% of op. labour			809
			S/T	3,309
Administration and General Overhead 70% Total Labour				5,415
Taxes and Insurance 2.5% of TIC				3,473
TOTAL OPERATING COSTS				23,482

The main area where technological improvements are needed is in wood gasification using either the steam-blown or oxygen-blown process. Further development is needed to:

- sustain operation of an oxygen or steam gasifier at a wood feedrate of at least 250 ODt/d;
- ensure that the gas composition and yield of gas are sufficiently stable to be compatable with gas modification and methanol synthesis processes;
- integrate a pilot-scale gasifier with a methanol synthesis train to develop and test operation and control of a complete methanol-from-wood plant.

Numerous improvements to wood gasifiers would be of benefit to the viability of methanol production from wood. These include increasing the operating pressure of the gasifier, reducing or eliminating the level of tar and oil leaving the gasifier, reducing feedstock preparation, and, for steam gasification, developing catalysts to optimize the composition of the crude synthesis gas. In the area of pressurized gasifier operation, oxygen and steam processes are being developed to operate with gasifier pressures between 1,000 kPa and 2,000 kPa. Significant reductions in compressor power requirements, and therefore operating costs, would occur if this pressure could be increased to upwards of 7,000 kPa. This is not expected to occur in the near future, since the main thrust of current work is to develop complete pilot plants to operate at moderate pressure. Higher pressure operation would be an evolutionary advancement. Reduction in the amount of feedstock preparation required upstream of the gasifier benefits a methanol process by reducing capital and operating costs. Presently, the Wright-Malta process requires minimal feedstock preparation compared to alternative fluidized-bed oxygen- and steam-blown gasification processes. The greater amount of feedstock preparation of some of these alternatives may prove to be counterbalanced by improved gasifier performance, such as steadier operation, improved gas yields, lower tar and oil yields, etc. There are presently insufficient data to clearly identify the best of the many gasifier alternatives. Reduction of tar and oil yields leads to a reduction of both capital and operating costs for gas cleanup. There are almost no published data for the level of particulate matter and condensible hydrocarbons in the crude synthesis from a wood gasifier, although general trends are evident. For example, fluid-bed units yield a gas having a relatively high concentration of particulate matter, but a low concentration of condensibles; updraft gasifiers differ by having lower levels of particulate matter, but higher levels of condensibles; while stirred-bed gasifiers (Wright-Malta) have low particulate matter and condensibles levels. In the final area of catalyst development, steam gasifiers stand to benefit substantially from the development of selective catalysts that promote high yields of synthesis gases. Work in catalyst development has been conducted at the Pacific Northwest Laboratory operated by Battelle.

A reduction in the power requirements for methanol synthesis may be possible with commercialization of the Chem Systems methanol synthesis process. This reduction would enable a reduction in the capital cost of portions of the plant and, depending on the cost of the new process, may lead to lower methanal production costs.

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CHAPTER 6 - PRODUCTION OF ETHANOL

6.1 Process Components

Wood is just one of the numerous carbohydrate raw materials which can be converted to ethanol. Wood is highly complex and requires extensive pretreatments compared to starch crops like corn, or sugar crops like cane.

The major steps in ethanol production by fermentation are (Figure 6-1):

- pretreatment of raw materials to release the sugars;
- fermentation of the sugars;
- separation and purification of the ethanol from the brew by distillation.

Pretreatment steps can be divided further into three areas:

- simple mechanical treatments to break up the raw material, reduce size, etc.;
- physical processes to separate the cellulose from other constituents (eg. lignin);
- conversion of the cellulose to sugars by hydrolysis (by chemical or biological agents).

There are several different routes to ethanol-from-wood, as shown in Figure 6-2. These pretreatment and hydrolysis steps are relatively unproven technology for wood feedstocks, while the back-end operations of fermentation and ethanol distillation are established technology (as in conventional brewing and distilling practice).

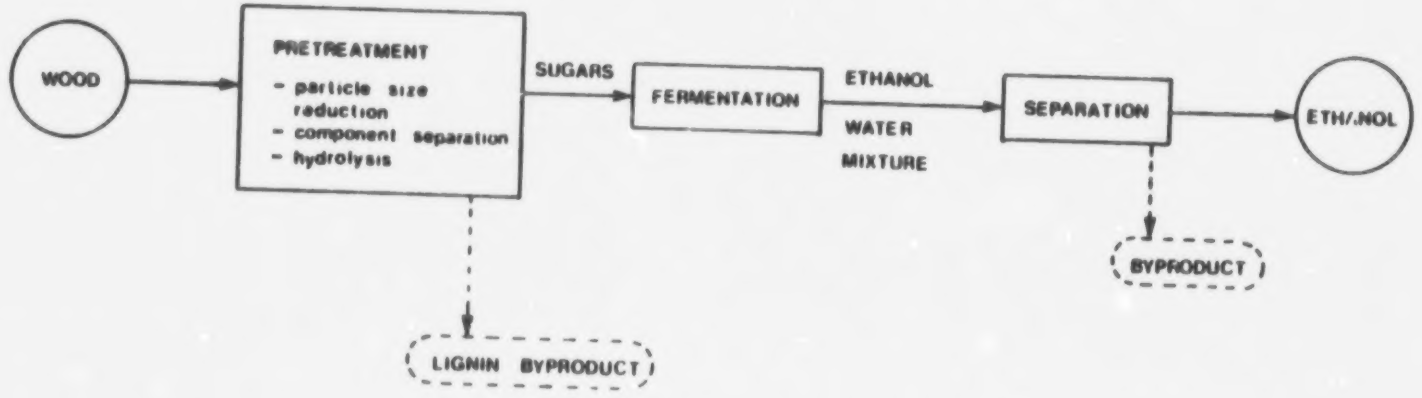

WOOD
PRETREATMENT
- particle size reduction
- component separation
- hydrolysis
SUGARS
FERMENTATION
ETHANOL
WATER
MIXTURE
SEPARATION
ETH/.NOL
LIGNIN BYPRODUCT
BYPRODUCT

FIGURE 6-1 PROCESSING STEPS IN ETHANOL-FROM-WOOD

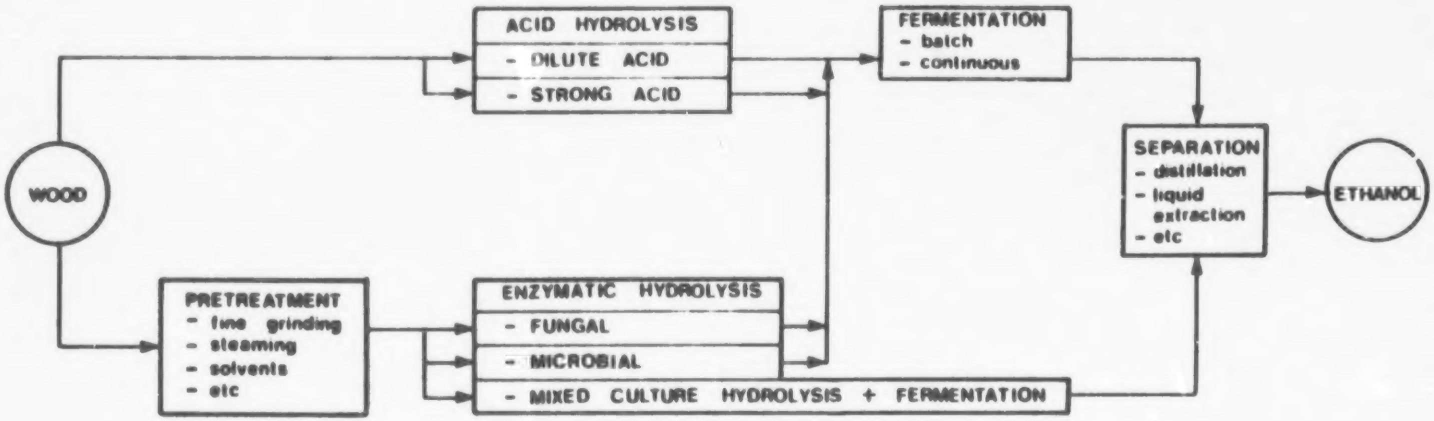

WOOD
ACID HYDROLYSIS
- DILUTE ACID
- STRONG ACID
PRETREATMENT
- fine grinding
- steaming
- solvents
- etc
ENZYMATIC HYDROLYSIS
- FUNGAL
- MICROBIAL
- MIXED CULTURE HYDROLYSIS + FERMENTATION
FERMENTATION
- batch
- continuous
SEPARATION
- distillation
- liquid extraction
- etc
ETHANOL

FIGURE 6-2 ALTERNATE PROCESSING ROUTES TO ETHANOL FROM WOOD

(a) Hydrolysis of Wood

The chemistry of liquid fuels from wood is mainly controlled by the chemistry of the different components of wood, i.e. cellulose, hemicellulose, and lignin (Table 6-1).

When wood is hydrolyzed by acidic or enzymatic agents, the cellulose polymer breaks down into 6-carbon sugar units (hexoses), while the hemicelluloses mainly form 5-carbon sugars (pentoses), as shown in Figure 6-3. The lignin does not break down into any sugars, but forms complex macromolecules. The exact nature and usefulness of the by-product lignin depends on the hydrolysis method.

Only the hexose sugars from cellulose may presently be fermented to ethanol using commercial technology. The low yield of these hexose sugars combined with the degradation of hexoses during hydrolysis results in an ethanol yield of 20 to 30% by weight. By comparison, the methanol-from-wood route has yields of 40 to 50% by weight because the other components of wood (hemicellulose and lignin) contribute to the synthesis gas.

The pentose sugars from hemicellulose cannot presently be fermented to ethanol with normal yeasts, although numerous efforts towards development of microorganisms capable of pentose fermentation are being made. Pentose fermentation could increase the total ethanol yield by up to one third.

(i) Acid Hydrolysis

The primary advantage of acid hydrolysis is that it has been used commercially with wood feedstocks and has more recently been refined in pilot-scale operations for wood feedstocks.

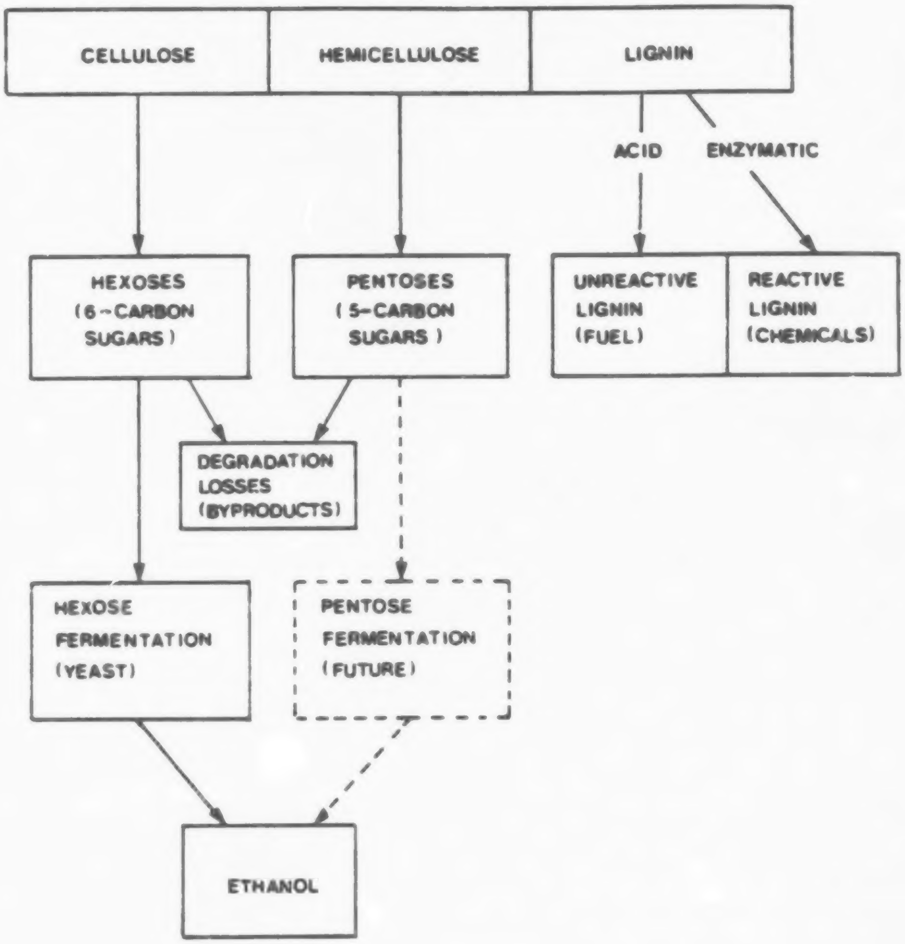

CELLULOSE
HEMICELLULOSE
LIGNIN
ACID
ENZYMATIC
HEXOSES (6-CARBON SUGARS)
PENTOSES (5-CARBON SUGARS)
UNREACTIVE LIGNIN (FUEL)
REACTIVE LIGNIN (CHEMICALS)
DEGRADATION LOSSES (BYPRODUCTS)
HEXOSE FERMENTATION (YEAST)
PENTOSE FERMENTATION (FUTURE)
ETHANOL

FIGURE 6-3 MAJOR REACTICN ROUTES OF WOOD COMPONENTS DURING HYDROLYSIS AND FERMENTATION

TABLE 6-1

BASIC COMPONENTS OF WOOD

	Polysaccharides			
	Cellulose (wt %)	Hemicellulose (wt %)	Lignin (wt %)	Extractives (wt %)
Softwoods	45	15 to 20	30	<10
Hardwoods	45	20 to 30	15 to 20	<10

Acid hydrolysis has the disadvantage of:

- low sugar yield;
- corrosion problems;
- high acid requirements;
- difficulty of acid recovery or disposal;
- low value of by-products (unreactive fuel-grade lignin);
- high capital expense.

No major pretreatments of wood are required prior to acid hydrolysis. Wood chipped to a controlled particle size is all that is needed for acid hydrolysis (like kraft pulping). Some steam treatment may also help to soften-up the chips and speed acid hydrolysis. Acid hydrolysis of wood evolved along two paths:

- dilute acid hydrolysis at high temperatures (sulphuric acid);
- strong acid hydrolysis at low temperatures (sulphuric and hydrochloric acids).

Both systems have been used, but the dilute acid route has reached a higher state of commercial application.

The dilute acid hydrolysis route uses 0.5% to 2% sulfuric acid at 175°C, which favours the hydrolysis reactions rather than the sugar degradation reactions. The early plants were simple batch processes without liquor circulation and did not produce more than about 25% of the theoretical sugar yield on wood. Development of a stagewise technique where the hydrolyzate is removed from the digester before the maximum yield of sugar is attained and fresh acid added improved on this process, resulting in a greatly increased yield of sugars.

An extension of this stagewise technique is the Scholler process in which the sugars formed during hydrolysis are rapidly removed from the reaction zone to minimize their further decomposition. The yield of sugar reaches 50% to 53% of theoretical for this process, leading to a yield of about 200 litres of ethanol per tonne of oven-dry wood.

A 30 tonne/day ethanol Scholler process was operated in Switzerland by the Inventa Company at Ems, Switzerland, from 1941 to 1956 (Mendelsohn and Wetstein). Process improvements have recently been developed by them on a pilot scale, in response to renewed interest in ethanol production from wood. A commercial design of their semi-continuous pulse-percolation hydrolysis process is now being promoted in conjunction with their continuous fermentation design.

The Madison process is an improvement of the Scholler process. It is a semi-continuous process which avoids prolonged retention of sugars under acid conditions at high temperatures to reduce degradation. The yield of this improved process is about 250 litres per tonne of wood.

The New Zealand Forest Research Institute (NZ FRI) renewed interest in the Madison process in the late 1970s. A pilot plant was operated at the Rotorua laboratory during 1979 to 1980 (Whitworth). A 12 tonnes ethanol/day prototype plant is reported to be currently under construction at a sawmill site there. The NZ FRI has separately licensed the technology to Ultrasystems Inc. of San Francisco for a possible larger demonstration prototype in North America.

A continuous process using high temperature and short resistance times has been developed to a 1 ton/day demonstration plant stage at New York University (Brenner and Rugg). A slurry of sawdust or newsprint is treated in a twin screw extruder with a 0.5% sulfuric acid at 3.5 MPa and 230°C for 20 seconds. Glucose yields of 60% are claimed. Another extrusion process has been researched at Dartmouth College (Thompson and Grethlein). Use of strong acids at lower temperatures overcomes the inherent problem of glucose degradation in the dilute acid/high temperature process. Strong acid processes depend on disruption of the crystalline structure of the cellulose by solution or swelling. The cellulose can then be rapidly hydrolyzed at temperatures low enough to avoid degradation. However, these processes require higher capital costs for corrosion-resistant equipment and higher operating costs associated with acid recovery and loss.

Strong acid hydrolysis of wood has been based mainly on hydrochloric and sulfuric acids because of their lower cost. Other acids such as nitric, formic, hydrofluoric, and phosphoric acids are also effective. Hydrochloric acid has been predominant since it is volatile and more readily recovered than sulfuric acid. The only commercial strong-acid wood hydrolysis plants used concentrated hydrochloric acid; this is referred to as the Bergius process. Several concentrated sulfuric acid processes have been researched but never commercialized.

The Bergius process plants were operated in Germany during World War II. This process used a countercurrent stream of hydrochloric acid at ambient temperature or below, that passed successively over previously treated and fresh wood chips. After vacuum distillation to recover the acid, the sugar oligomers were hydrolyzed to monomers.

(ii) Enzymatic Hydrolysis

Enzymatic hydrolysis has the following advantages over acid hydrolysis:

- higher sugar yields (less degradation of sugars);
- simpler equipment (lower temperatures and less corrosive process fluids);
- hemicelluloses are not degraded (potential for separate pentose fermentation);
- compatible with fermentation (can hydrolyse and ferment simultaneously);
- lignin residues remain in active form (suitable for chemical derivatives).

The major disadvantages of enzymatic hydrolysis are:

- requires extensive wood pretreatment;
- presently, only feasible in laboratory or pilot scale (no commercial experience);
- sensitive to wood feedstock.

Like all biological processes, the rates of reaction of enzymatic hydrolysis tend to be slower than acid hydrolysis. Longer residence times and larger process vessels are thus necessary, but operating conditions are less severe.

Enzymatic hydrolysis requires more complex pretreatments to break-up the wood than acid hydrolysis. Pretreatments such as fine grinding, steam explosion and solvent treatment have been tried. These are necessary to allow more complete access of the enzymes to the cellulose. The lack of an inexpensive pretreatment to improve enzyme accessibility has been a major stumbling block to the application of enzymes.

Three distinct enzyme hydrolysis routes exist (Figure 6-2):

- fungal enzyme hydrolysis;
- microbial enzyme hydrolysis;
- mixed cultures to do hydrolysis and fermentation together (simultaneous saccharification and fermentation).

For all enzyme hydrolysis processes for wood feedstock routes pretreatment is essential. Among the more promising pretreatment are:

- Steam explosion techniques such as those developed by Stake Technology and Iotech. These rely on the acetic acid released during fast steam and wood mixing in a "gun" to promote subsequent hydrolysis digestibility.
- Selective solvents: Purdue University has developed certain solvents which selectively dissolve and isolate the cellulose from wood for subsequent enzymatic treatment.

Other pretreatments which have been tried, but have not been found to be applicable to enzymatic hydrolysis are:

- fine grinding;
- gamma radiation;
- alkali swelling agents;
- conventional chemical pulping;
- sulfur dioxide treatment.

(b) Fermentation

Fermentation is the production of ethanol by yeasts consuming hexose sugars. Most of the requirements for such large scale industrial fermentation of sugars obtained by wood hydrolysis can be met from established technology.

Application of fermentation to industrial production of fuel grade ethanol from wood sugars requires technological changes of the following nature:

- increased scale of production;
- continuous rather than batch reactors;
- higher energy efficiency;
- different by-product handling.

Several alternative fermentor designs exist, including gas-lift fermentors, continuous tower fermentors, and fixed-film fermentors. For large-scale and continuous operations, the gas-lift fermentors are particularly attractive since they are not restricted by size and have low power requirements. Fixed-film fermentors are under development and are presently not available commercially.

During fermentation, an excess of water is required to ensure the final ethanol concentration does not exceed about 10% and inhibit the fermentation process. Consequently, a large quantity of process water must be handled, resulting in two major negative impacts on the process plant:

- excessive effluent disposal costs;
- excessive energy consumption in subsequent ethanol-water separation by distillation.

Several methods are available to reduce the process water demand and energy consumption, such as ethanol-tolerant yeasts, vacuum fermentation, and Alfa-Laval's Biostil process.

Alfa-Laval has developed a fermentation process having a lower energy requirement and an improved yield (Figure 6-4). This process involves fundamental changes to the substrate feeding, fermentation, and distillation steps. Instead of the fermentation being ethanol-concentration limited, it is limited by the concentration of accumulated soluble non-fermentables present. Process water required is as low as 60% of conventional fermentation, and the ethanol yields are up to 5% higher. The single continuous fermentor is controlled to a maximum ethanol concentration of 5% by continuous removal during its formation. This is well below the terminal ethanol level and thus, promotes rapid fermentation, full assimilation of sugars, and reduces byproduct formation. The low ethanol concentration permits higher solute concentrations of other components. This higher total operating concentration of 40 to 50% reduces the process water dilution requirement.

The Biostil process ethanol yields are claimed to be higher because:

- sugar losses are lower in fermentor outflow;
- non-volatile by-product formation is lower;
- yeast reuse reduces the sugar demand for fresh yeast growth.

Resistance to culture infection has been built into the system by:

- recirculation of pasturized fermentation liquid;
- high dissolved solids concentration in the fermentor and absence of residual sugar inhibits bacterial growth;

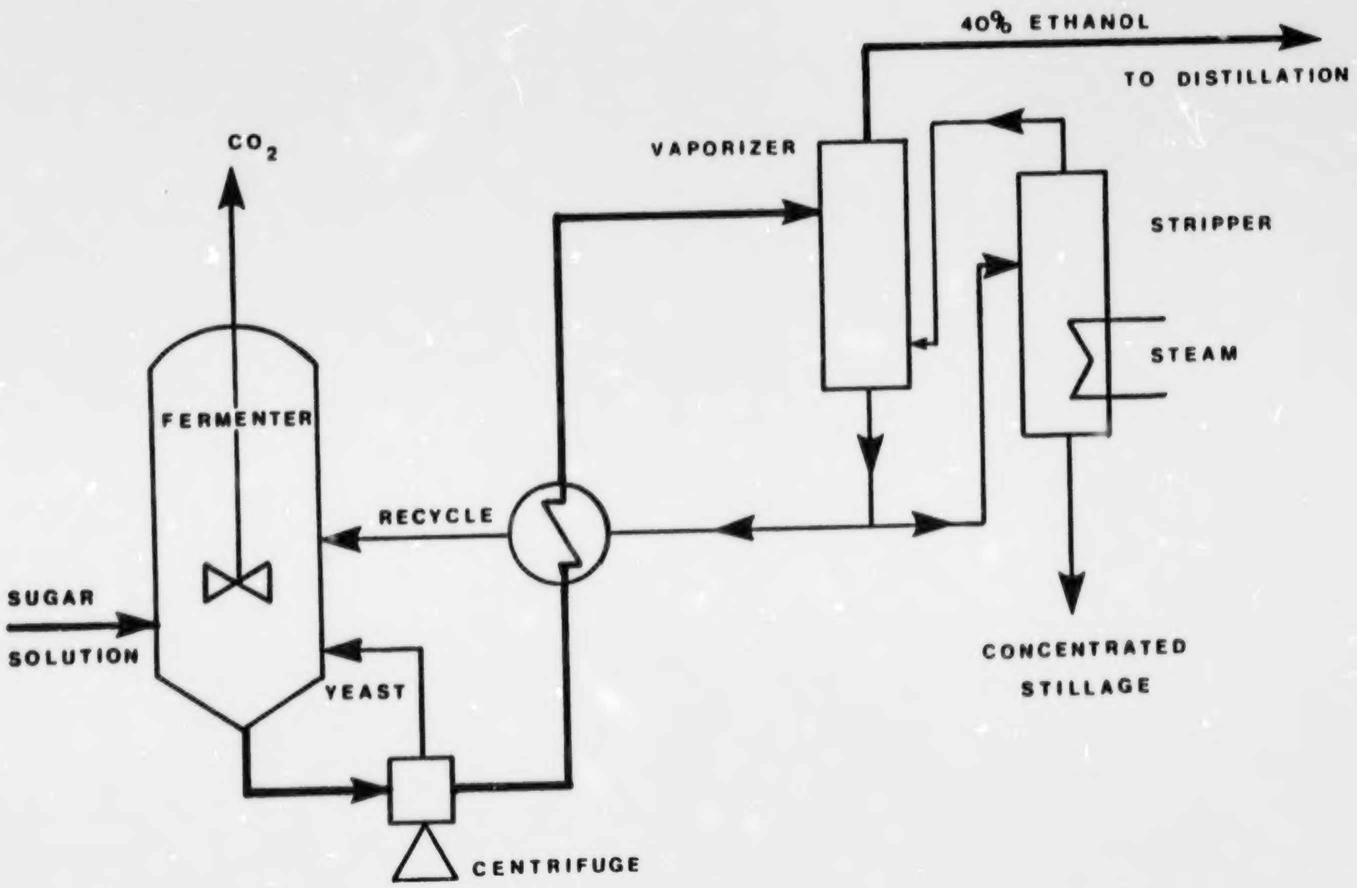

40% ETHANOL
TO DISTILLATION
CO$_2$
VAPORIZER
STRIPPER
STEAM
FERMENTER
RECYCLE
SUGAR
SOLUTION
YEAST
CONCENTRATED
STILLAGE
CENTRIFUGE

FIGURE 6-4 THE BIOSTIL PROCESS (ALFA - LAVAL)

- yeast strain chosen to be tolerant to organic acids generated by bacterial infections.

The first commercial plant was installed for molasses fermentation in Australia in 1981.

Use of the Biostil process as the fermentation process block of an ethanol-to-wood process appears desirable to reduce plant energy requirements.

(c) Ethanol Separation

Wood hydrolysis and fermentation produces a dilute mixture of ethanol and water as well as other minor compounds. The ethanol has to be separated from this "beer" before use as a fuel, normally by distillation.

Two grades of ethanol are usable as engine fuels. To blend ethanol with gasoline anhydrous ethanol is necessary to avoid phase separation. For neat ethanol fuel use, a partially separated azeotropic mixture consisting of 5% water and 95% ethanol can be utilized.

Fermenting to ethanol concentrations above 10% is not normally possible because of the inhibiting effect that increasing ethanol content has on yeast growth. The lower the starting ethanol concentration, the higher the heat energy required to perform the separation, as shown for conventional distillation in Figure 6-5.

Distillation is largely established technology. No major discussion is relevant in this report. However, highlighting separation techniques for distillation modifications and alternatives to reduce energy consumption is appropriate.

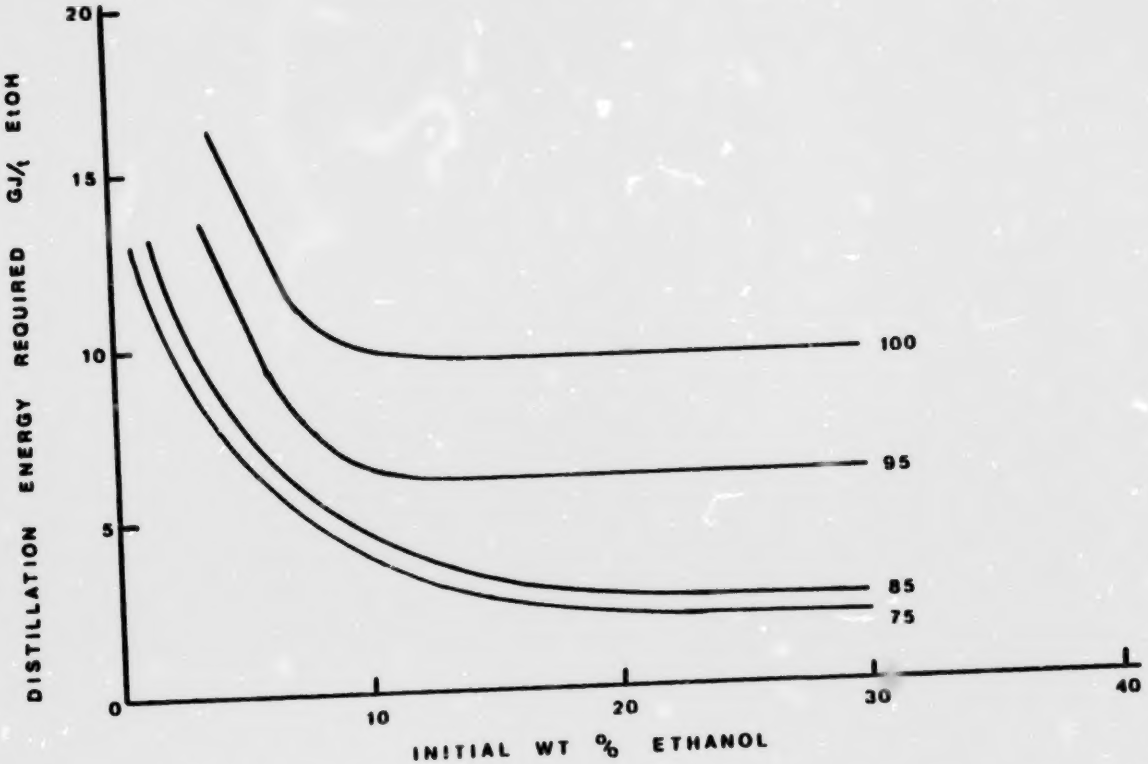


FIGURE 6-5 ETHANOL DISTILLATION ENERGY AS A FUNCTION OF INITIAL AND FINAL ETHANOL CONCENTRATION

(i) Distillation

The distillation of ethanol from water has to be done in two stages:

- conventional distillation to 95% concentration;
- azeotropic dehydration to from 95% to 100%.

Azeotropic distillation involves the use of a relatively volatile component such as benzene or cyclohexane as an entraining agent. This takes the water overhead, after which the benzene is separated in a stripping column for reuse.

Production of chemical grade ethanol requires further distillation to remove contaminants such as fusel oil.

Conventional distillation uses about 6.4 GJ/t of ethanol for a 10% initial concentration. Azeotropic distillation from 95% to 100% requires an additional 3.3 GJ/t resulting in a total energy requirement of about 10 GJ/t, about half of the total energy requirement of the complete wood-to-ethanol plant.

Several improvements to distillation technology are available to minimize energy use:

- vacuum distillation (in single or multiple towers);
- vapour recompression distillation.

Single column vacuum distillation can be used to break the azeotrope at pressures below 11.7 kPa; however, the total energy to go from 10% to 100% ethanol in one stage is 100% higher than conventional 2-stage distillation.

Multiple column distillation with successively decreasing pressures can do the separation up to the azeotrope with less than half the energy for single fractional distillation stage. When followed by azeotropic distillation, the total energy to get to 100% ethanol would then be only about 6 GJ/t (Fredrickson et al). However, the capital cost of multiple tower systems is higher.

Vapour recompression is conventional technology in the petroleum industry. It has significant energy savings by using the latent heat of overhead vapours in the reboiler. The distillation energy requirement for such a system operating to a 95% concentration would be about 0.7 GJ/t, a substantial reduction from 6.4 GJ/t.

(ii) Alternatives to Distillation

Other less conventional separation techniques are possible to reduce the energy requirements of distillation, including:

- liquid carbon dioxide extraction;
- solvent extraction;
- low temperature blending with gasoline;
- molecular sieve absorption;
- reverse osmosis;
- dehydrating solids.

The relative energy requirements of these techniques are shown in Table 6-2, compared to conventional 2-stage distillation and the other distillation improvement schemes (Eakin et al).

6.2 Base Case Plant Analysis

(a) Plant Design Basis

(i) Plant Size and Location

The same criteria for the selection of a plant size for ethanol production was used as was used for the methanol plant. The upper limit on the supply of mill residues in one location was set at 270,000 ODt/y or 818 ODt/d, based on 330 days per year. This supply could probably be increased to 1,100 ODt/d if residues were

Table 6-2

ENERGY CONSUMPTION FOR DIFFERENT ETHANOL SEPARATION METHODS

Type of Separation	Ethanol Concentration Initial	Ethanol Concentration Final	Process	Energy GJ/t
Complete	10%	100%	-Conventional "Dual" Distillation	9.7
			-CO_2 Extraction	2.8-3.0
			-Solvent Extraction	1.27
			-Vacuum Distillation	13.0
to Azeotrope	10%	95%	-Conventional Distillation	6.4
			-Vapour Recompression	0.7
			-"Multi-Effect" Vacuum	2.54
Azeotropic	95%	100%	-Conventional Azeotropic Distillation	3.32
			-Dehydrating Solids	0.42
			-Low Temperature Blending with Gasoline	1.06
			-Molecular Sieve	1.7-2.2
Other	5%	10%	-Reverse Osmosis	0.18

transported in to the plant from outside the immediate vicinity of the plant, but at higher cost.

An ethanol plant producing 150 t/d was chosen as the base case since it has a total wood of 750 ODt/d, leaving some unconsumed residues from the design upper limit.

The plant is assumed to be located in the vicinity of Williams Lake or Kamloops or any other location which offers a railroad link for transport of supplies and products, has a population in excess of about 10,000 people, and is near a natural gas pipeline.

No allowance has been made for site-specific costs such as land, specific site development, etc.

(ii) Wood Feedstock Description

The feedstock was assumed to be a mixture of hogged and chipped wood, preferably very low in bark content, received from mills without any other type of preparation. Pilot tests are needed to define the effect of bark content on the Inventa process. This feedstock would likely contain foreign material such as dirt, rock, and some tramp metal that would have to be removed during handling at the plant. The moisture content of the wood was taken to be nominally 45%, wet basis.

(iii) Ethanol Specifications

The minimum ethanol content of the final product was taken to be 99.3 vol %.

(iv) Hydrolysis, Fermentation, and Distillation

The complete plant marketed by Inventa for producing ethanol from wood was considered in this study. This plant includes the three main processes--hydrolysis, fermentation, and distillation--that have been tailored by Inventa to suit a wood feedstock. The Inventa plant components are described in some detail in later sections.

(v) Utilities

Electricity, water, and natural gas for the plant are available at the plant gate. The plant is designed to make maximum use of the lignin and stillage by-products for fuel to generate steam for process use and electricity generation. Natural gas is needed for use as a back-up fuel in the boiler and for plant startup.

(b) Selection and Description of Plant Components

The main process units for an ethanol plant are:

- hydrolysis;
- fermentation;
- separation of ethanol.

The balance of the plant consists of facilities for steam and power generation, process water supply, waste water treatment, by-products processing, and general service.

(i) Hydrolysis Process

Selection of the method of hydrolysis is a critical decision for design of a plant producing ethanol from wood. The remaining processing steps have been well proven with other feedstocks and are expected to be readily transferable. No commercial experience with wood hydrolysis has been gained in recent years in the Western World. Acid hydrolysis is presently considered to be the only viable choice for commercial application in the near future. Enzymatic hydrolysis has not been tested at a pilot scale, and consequently, commercialization is some time away.

Of the several acid hydrolysis processes under development for wood feedstocks the dilute sulfuric acid process has received the most attention. Dilute sulfuric acid hydrolysis systems for wood are presently being proposed for commercial applications by Inventa AG of Zurich, Switzerland, and the New Zealand Forest Research Institute. Inventa markets a process based on the earlier Scholler hydrolysis process while New Zealand Forest Research Institute markets a modified Madison process.

The Inventa Process appears to be nearest to commercialization, based on experience gained with a pilot plant operated with a wood feedstock, company experience with similar chemical plants, and company preparedness for marketing.

Inventa operated a wood-fed plant in Switzerland from 1941 to 1956 that used the Scholler acid hydrolysis process and their own fermentation process to produce 30 t/d of ethanol. In the 1970s, Inventa undertook pilot plant studies to improve the hydrolysis process for wood feedstocks (Mendelsohn and Wetstein). This unit processed 2 t/d of wood. Inventa is presently marketing turn-key plants for wood feedstocks worldwide, although no commercial plants are currently operating. Studies of application of the process in North America have been performed by Inventa's agent, Pedco of Cincinatti (Pedco International Inc.).

Steps in the Inventa Process are shown in Figure 6-6.

The solids-handling and wood-preparation steps that are required depend on the type and condition of the wood feedstock, for example, whether the wood is roundwood, chips, or hog fuel. Bark-free wood chips and sawdust are preferred since bark compounds interfere with the fermentation process, reducing ethanol yields. The sensitivity of fermentation to bark content of the feed is a very important

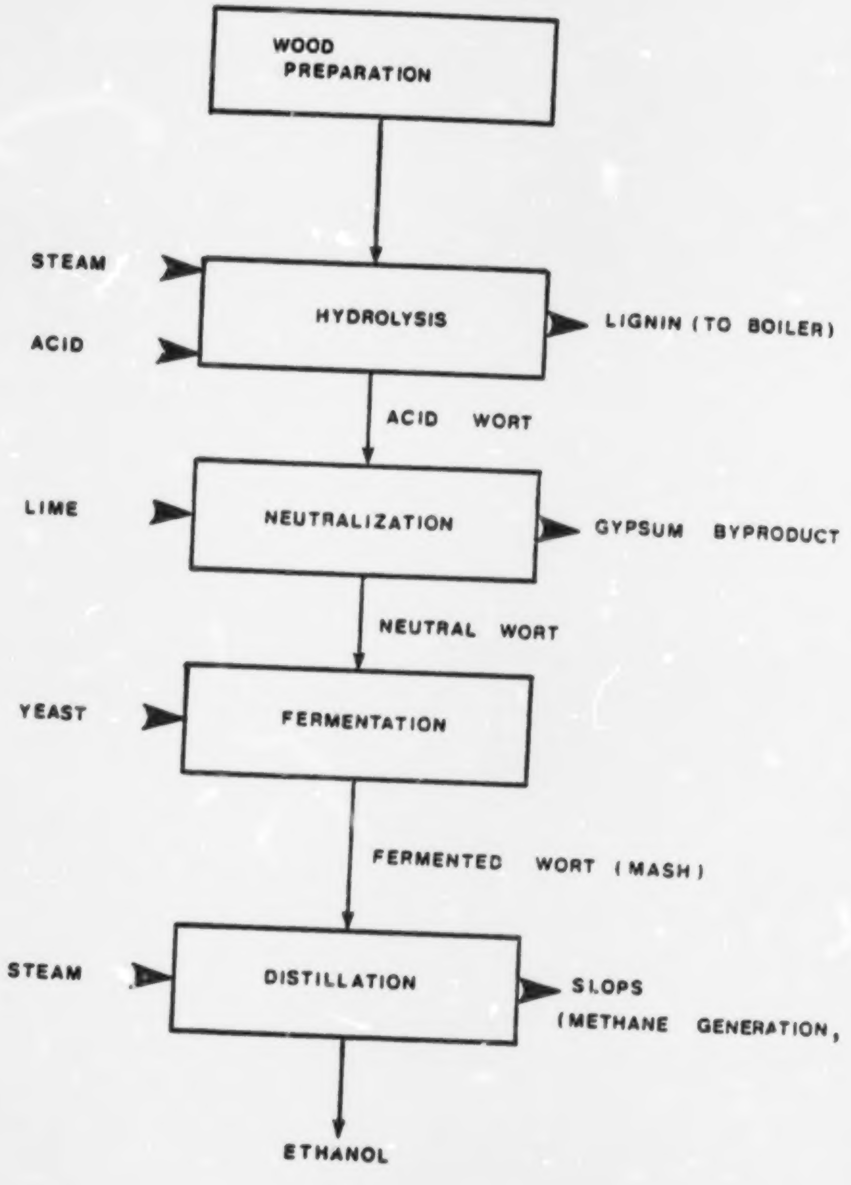

WOOD PREPARATION
STEAM
ACID
HYDROLYSIS
LIGNIN (TO BOILER)
ACID WORT
LIME
NEUTRALIZATION
GYPSUM BYPRODUCT
NEUTRAL WORT
YEAST
FERMENTATION
FERMENTED WORT (MASH)
STEAM
DISTILLATION
SLOPS
(METHANE GENERATION,
ETHANOL

FIGURE 6-6 INVENTA PROCESS MODULES

consideration for any use of wood residues from mills as feedstocks, since these will normally have substantial bark contents.

The hydrolysis reactors are batch digestors in which liquid is percolated down through solids (Figure 6-7). There are several reactors, the number depends on the type and quality of the feedstock, that operate in a semi-continuous mode with feeding occurring on staggered time cycles of about 8 hours duration.

In the course of a cycle, the reactor is first filled with wood and pressurized to 1,000 kPa. Steam is introduced to flush out air and preheat the chips. The contents are exposed to pulses of dilute sulfuric acid (0.6%) in small successive flows at timed intervals. Each flow is removed from the base of the vessel before the next is introduced. A preliminary hot water pulse is used to swell the chips and promote access of the acid and removal of the sugars.

The starting temperature for hydrolysis is 140°C at which the hemicelluloses are released as pentose sugars over a 40- to 60-minute period. At this temperature, the pentoses do not degrade excessively to furfural. Subsequently, the temperatures of the pulses are raised successively to 180°C. Cellulose progressively hydrolyzes to hexose sugars over a 150- to 170-minute period.

The overall ratio of liquor to wood is kept at about 10:1 on a weight basis, giving a 3 to 4 vol % fermentable sugar solution. This relatively low sugar concentration is well below the ethanol tolerance limit of the yeast.

The hydrolyzate liquor (wort) contains hexose and pentose sugars, residual acid, and minor components. This is pumped from the base

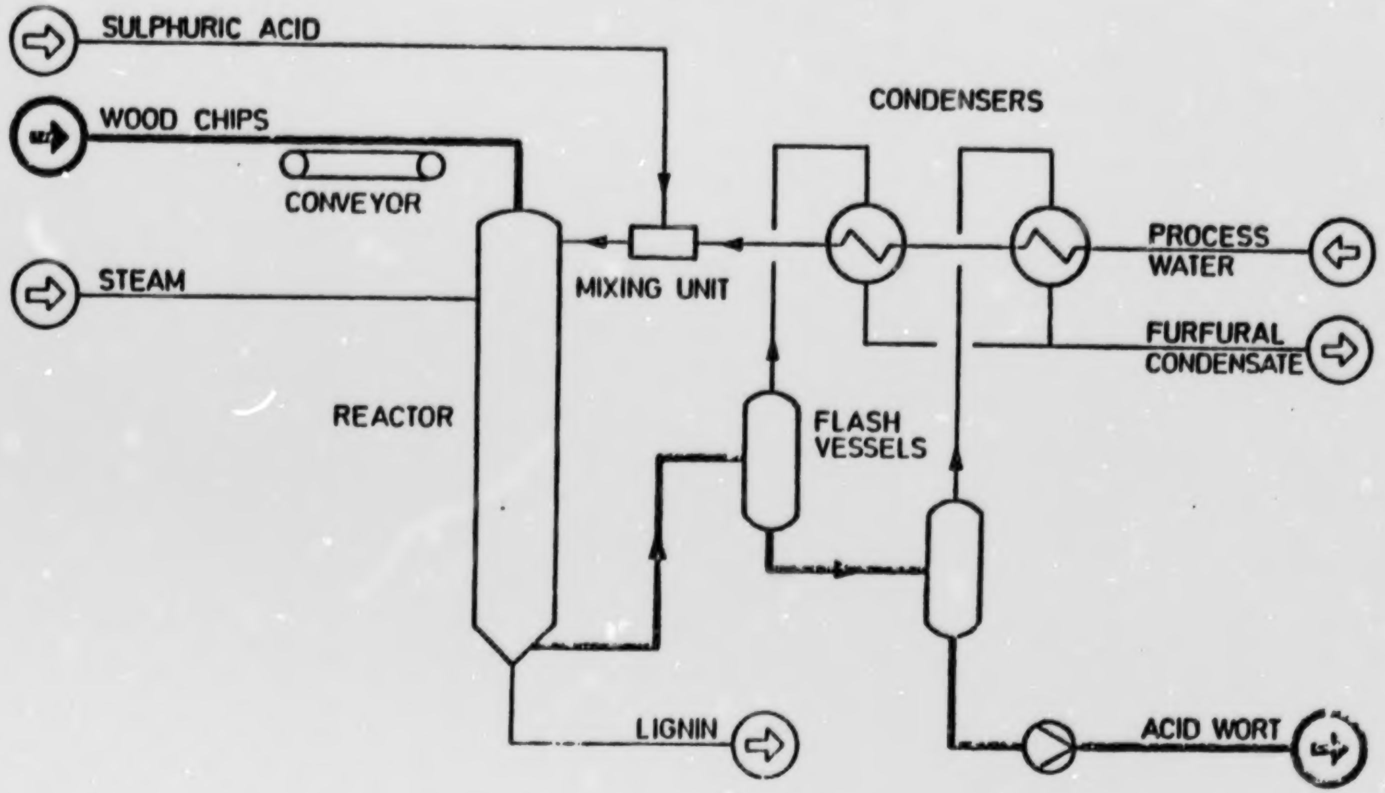

SULPHURIC ACID
WOOD CHIPS
CONVEYOR
STEAM
REACTOR
MIXING UNIT
CONDENSERS
PROCESS WATER
FURFURAL CONDENSATE
FLASH VESSELS
LIGNIN
ACID WORT

FIGURE 6-7 HYDROLYSIS PROCESS

of each reactor to a common flash system (Figure 6-7). The flash system:

- cools the liquor (to prevent further decompositon, and to prepare for neutralization);
- buffers the semi-continuous hydrolysis operations from the continuous fermentation operation;
- removes and recovers volatiles (furfural which otherwise interferes with fermentation);
- recovers flash steam energy (to preheat process water and augment distillation steam).

After hydrolysis is complete, indicated when the sugar concentration of acid pulses drops, the ligno-cellulose cake remaining in the reactor is washed with water to remove remaining sugars. The reactor is then depressurized and the lignin cake is removed.

A number of options exist for utilizing the lignin recovered from the hydrolyzer. After dewatering the preferred use for the lignin is for fuel to generate process steam. Briquetting or coking of the lignin could be performed for outside sale.

The acid wort discharged from the hydrolyzer must be neutralized; normally with limestone ($CaCO_3$). This is done in a stired tank as shown in Figure 6-8. Process conditions are chosen to minimize further decomposition of the sugars and to limit the solubility of the calcium sulphate formed during neutralization of the acid. Carbon dioxide released during the reaction is vented to atmosphere. Neutralization proceeds until the ph of the solution reaches 4; preserving some organic acids which are beneficial to fermentation.

Fine calcium sulphate precipitated during neutralization is separated from the liquor effluent in a centrifuge. This material may be used for gypsum board or a feedstock for conversion to fertilizer.

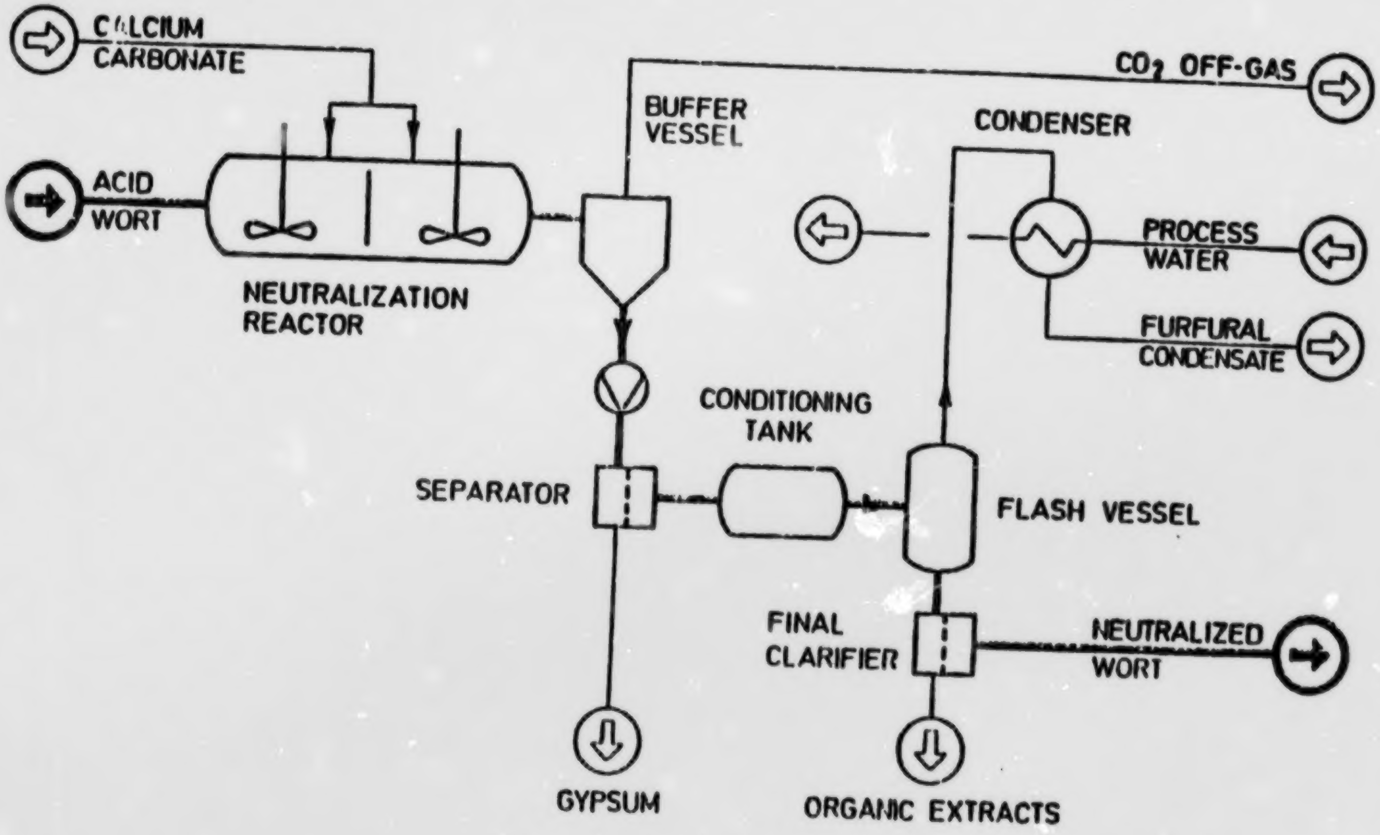

CALCIUM
CARBONATE
ACID
WORT
NEUTRALIZATION
REACTOR
BUFFER
VESSEL
CO_2 OFF-GAS
CONDENSER
PROCESS
WATER
FURFURAL
CONDENSATE
CONDITIONING
TANK
SEPARATOR
FLASH VESSEL
FINAL
CLARIFIER
NEUTRALIZED
WORT
GYPSUM
ORGANIC EXTRACTS

FIGURE 6-8 NEUTRALIZATION PROCESS

The sources of by-products in the ethanol plant and an indication of their potential uses are illustrated in Figure 6-9.

After gypsum separation, the neutral wort goes through a conditioning tank. This flocculates undesirable organic extracts and residual gypsum fines. A flash tank cools the liquor to 30°C and separates furfural from the wort. A final clarifier filters the organic and gypsum particles from the wort. The cooled, clarified wort is then ready for feed to the fermentation section.

Organic extracts and heavy metals from bark in the wood supply are detrimental to fermentation. With the high bark contents in hog fuel (typically 25%), the conditioning and cleaning steps would have to be expanded for increased removal capacity.

Furfural is produced as a by-product during hydrolysis (Figure 6-7) and acid neutralization (Figure 6-8) and may be upgraded to a commercial product by further processing (Figure 6-10).

The furfural condensates are fed to a stripping column where most of the water is removed. The furfural-rich phase is fed to a dehydration column for distillative separation. The furfural-rich water/furfural mixture is withdrawn from the base and purified in a rectifying column.

Furfural has a variety of end-uses (selective solvent, chemical intermediate, raw material for production of foundry resins, etc.) and has a market value of $1,500 Can/tonne. There is only one supplier in North America (Quaker Oats). An increase in supply may cause a price reduction.

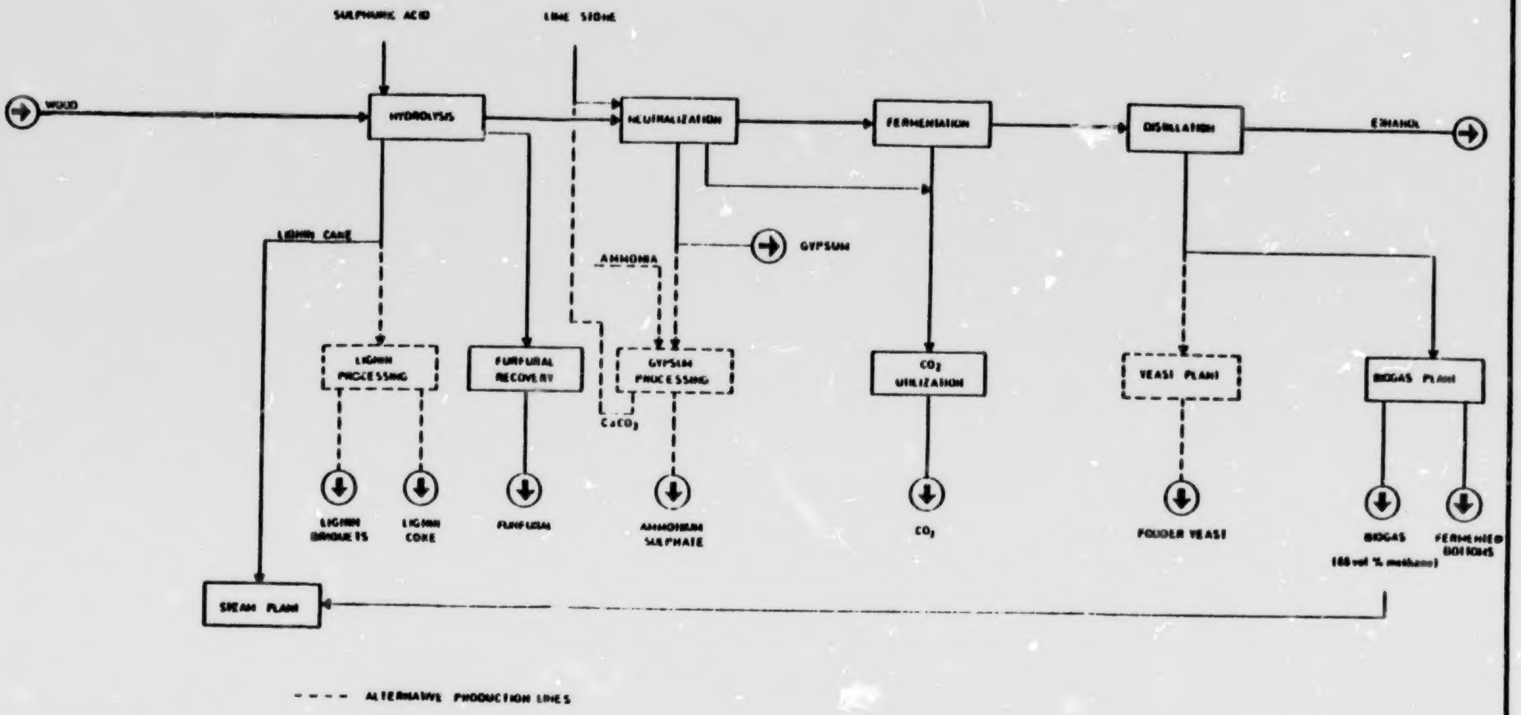

SULPHURIC ACID
LIME STONE
WOOD
HYDROLYSIS
NEUTRALIZATION
FERMENTATION
DISTILLATION
ETHANOL
LIGNIN CAKE
AMMONIA
GYPSUM
LIGNIN PROCESSING
FURFURAL RECOVERY
GYPSUM PROCESSING
$CaCO_3$
CO_2 UTILIZATION
YEAST PLANT
BIOGAS PLANT
LIGNIN BRIQUETTES
LIGNIN COKE
FURFURAL
AMMONIUM SULPHATE
CO_2
POWDER YEAST
BIOGAS
(68 vol % methane)
FERMENTED BOTTOMS
STEAM PLANT
ALTERNATIVE PRODUCTION LINES

FIGURE 6-9 BYPRODUCT USES IN INVENTA PROCESS

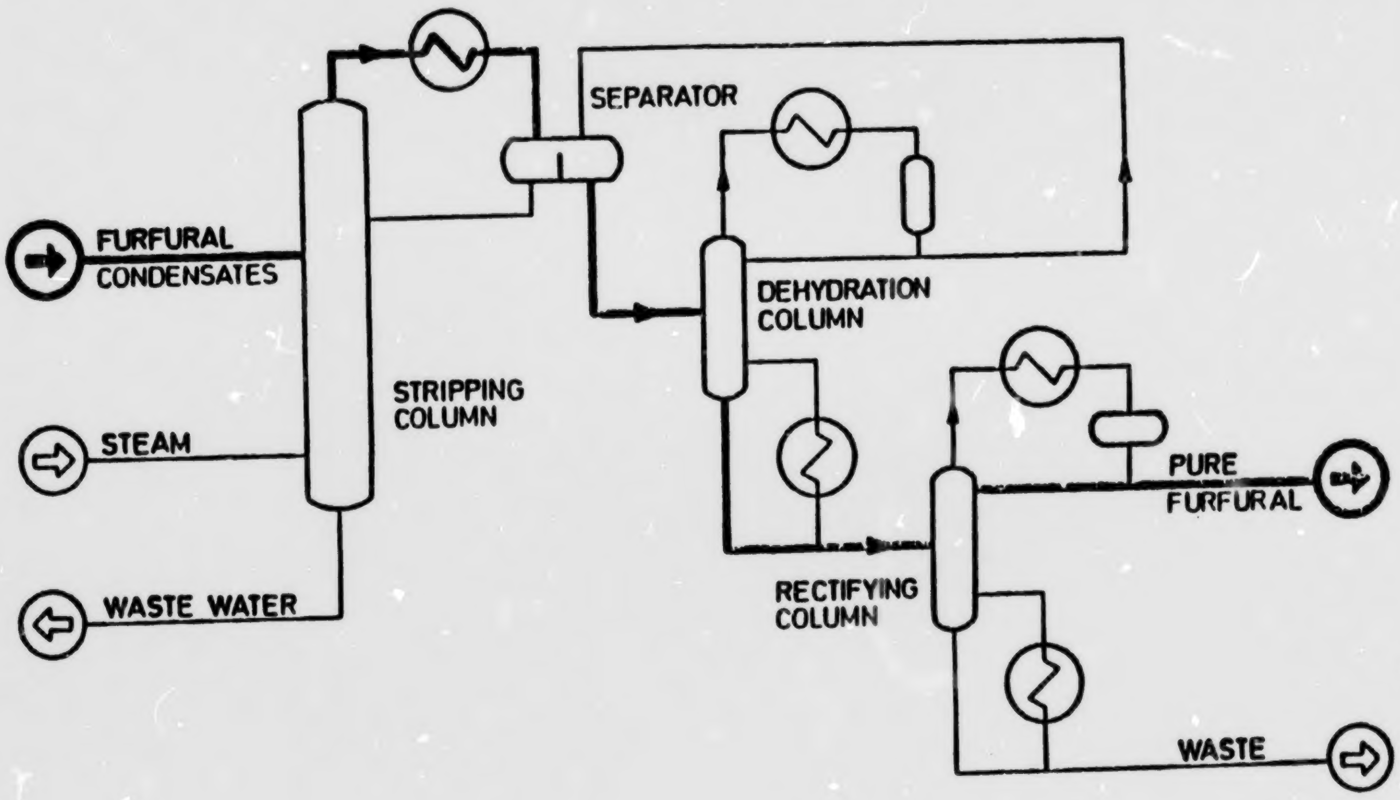

FURFURAL CONDENSATES
STEAM
WASTE WATER
STRIPPING COLUMN
SEPARATOR
DEHYDRATION COLUMN
RECTIFYING COLUMN
PURE FURFURAL
WASTE

FIGURE 6-10 FURFURAL PROCESSING

(ii) Fermentation Process

Continuous fermentation is superior to batch fermentation for commercial production of fuel-grade ethanol, and for this reason it was chosen for incorporation into the ethanol plant.

Inventa offers a continuous fermentation process that has been integrated with their semi-continuous acid hydrolysis and acid wort neutralization processes. The neutralized wort passes to fermentors arranged in series which yield a fermented wort (Figure 6-11). The reactors use an advanced gas-lift design and are arranged in two parallel production lines for operational flexibility. Carbon dioxide used for aggitation of the fermentors is recylced from the CO_2 off-gas stream.

A special strain of yeast developed by Inventa is used in the fermentors, along with nitrogen and phosphates needed as nutrients. The yeast is separated from the fermented wort with a filter, then recycled to the front end of the fermentor train to mix with fresh wort from the hydrolysis process.

In continuous fermentation systems contamination of the yeast by bacteria must be avoided. Fermentor sterilization is maintained in the Inventa continuous fermentation reactors by a system termed "cleaning-in-place". A slipstream of the yeast recycle (20%) is subjected to a special wash. This wash is necessary to maintain yeast metabolism efficiency, i.e.:

- inhibit the growth in the yeast of unwanted organisms from external sources;
- free surface membranes of colloidal yeast deposits from the wort liquor.

Yeast addition to replace inactive or dead cells is kept to a minimum to maximize ethanol yields. Inactive yeast is kept to a level of 3% for optimum operation.

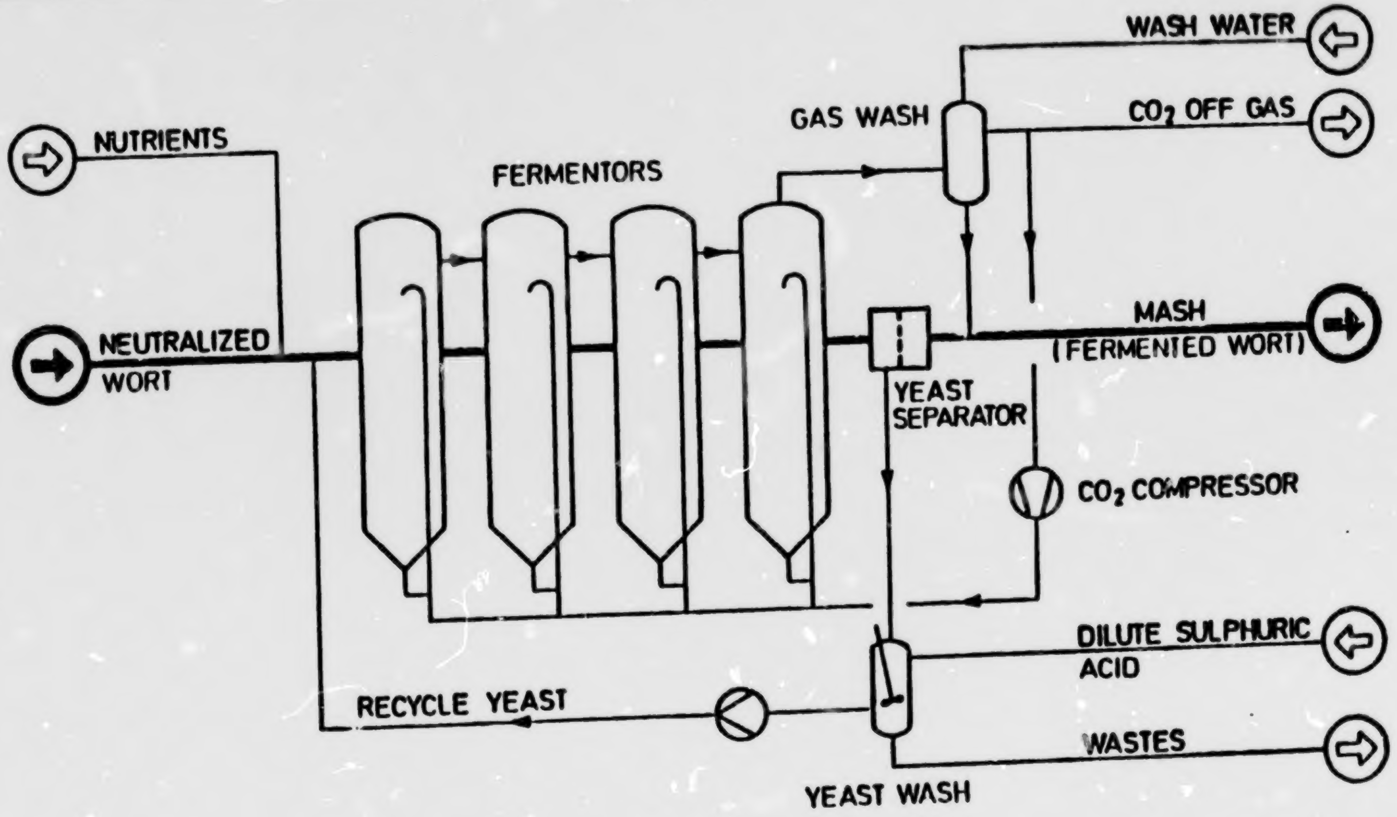

WASH WATER
GAS WASH
CO_2 OFF GAS
NUTRIENTS
FERMENTORS
NEUTRALIZED WORT
MASH (FERMENTED WORT)
YEAST SEPARATOR
CO_2 COMPRESSOR
DILUTE SULPHURIC ACID
RECYCLE YEAST
WASTES
YEAST WASH

FIGURE 6-11 FERMENTATION PROCESS

The fermentor product mash has about a 2% ethanol concentration for feed to the distillation section. Operation at this low ethanol level promotes optimum sugar-to-ethanol conversion by the yeast, but puts a high water separation and energy requirement on the subsequent distillation stage. The tradeoff between maximum ethanol production and increased energy consumption can be made by use of a multiple-effect distillation system and by using the process byproducts for plant fuel.

(iii) Distillation

Of the several commercial distillation technologies the multiple-effect distillation process has the lowest energy requirement. Inventa offers this type of distillation process as part of their plant design.

The Inventa distillation section uses four columns with successively decreasing operating pressures (Figure 6-12).

The neutralized wort enters the distillation section of the plant at the mash column. The overhead product from the mash column contains 15% ethanol and is sent to the rectifying column. The bottoms from the column are sent to a digester for fuel gas production. Steam is added to the mash column to assist ethanol separation.

In the rectifying column the ethanol is concentrated to 94 vol %. Fusel oils are removed as a side-stream for use as boiler fuel.

The 94% alcohol solution leaving the rectifying column is distilled with cyclohexane to send the residual water overhead as an azeotropic mixture and obtain a bottom product containing 99.3 vol % ethanol. The mixture of water and cyclohexane is passed to a stripping column for recovery of cyclohexane, which is then recycled to the azeotropic distillation column.

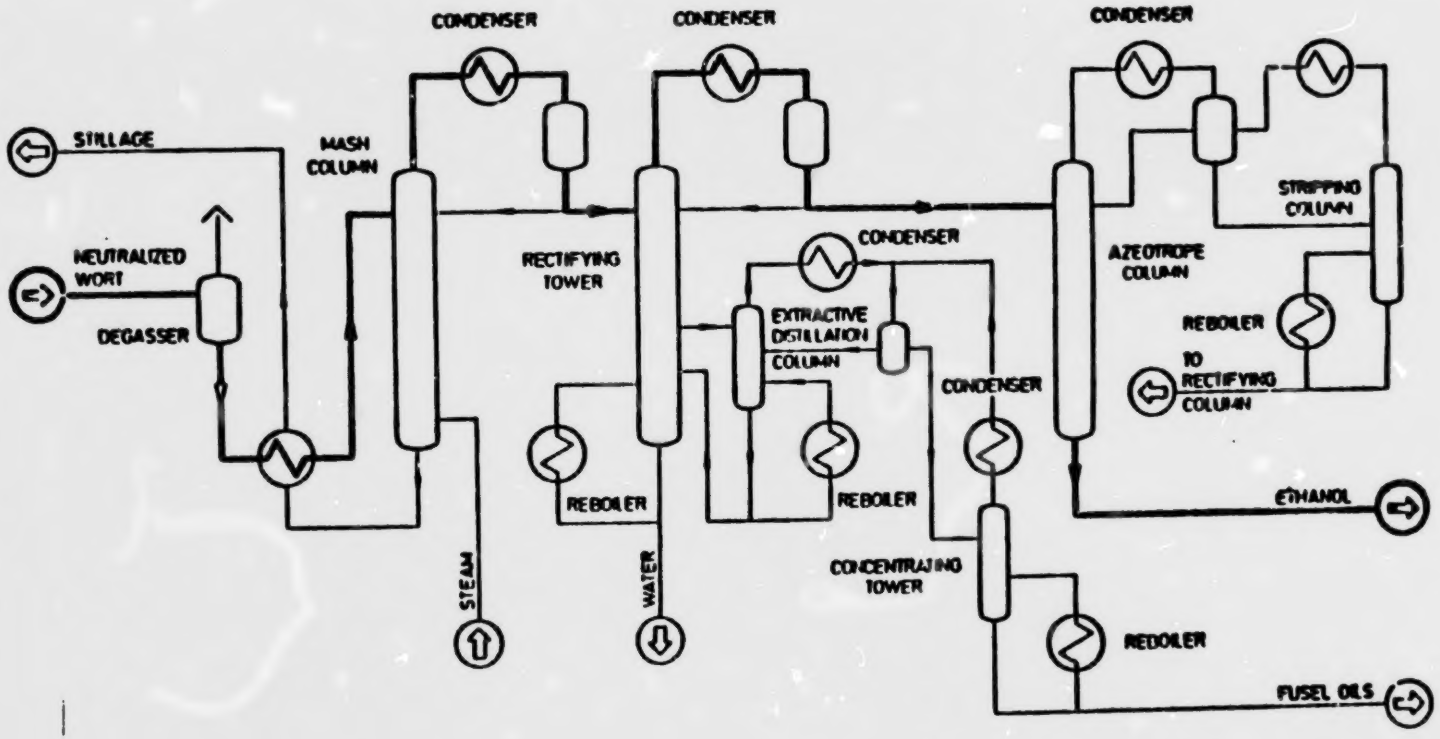

CONDENSER
CONDENSER
CONDENSER
STILLAGE
MASH COLUMN
NEUTRALIZED WORT
DEGASSER
RECTIFYING TOWER
CONDENSER
EXTRACTIVE DISTILLATION COLUMN
STRIPPING COLUMN
AZEOTROPE COLUMN
REBOILER
TO RECTIFYING COLUMN
CONDENSER
REBOILER
REBOILER
STEAM
WATER
CONCENTRATING TOWER
ETHANOL
REBOILER
FUSEL OILS

FIGURE 6-12 INVENTA DISTILLATION PROCESS MODULE

Removal of the fusel oil (high-boiling alcohols) is accomplished by withdrawing a sidestream with 60% alcohol content from the center of the rectifying column. This sidestream is passed to an extractive distillation column where the higher-boiling point constituents are stripped off. Recovered ethanol is returned to the rectifying column. The recovered fusel oil passes to a concentrating tower and then may be used as boiler fuel or sold. Methanol may also be separated from the azeotropic distillation column for mixing with ethanol or boiler fuel.

The bottoms of the rectifying column are used for generation of methane using an anaerobic digester (Figure 6-13). This biogas is used as boiler fuel.

Slops from the mash column are a 3% solution of pentose sugars and various accompanying products in water. This solution and smaller secondary feeds are processed in a methanization unit for bacterial conversion to biogas.

The digestor operates at 35°C with mesophilic bacteria and converts some 80% of the organics to gas. The gas yield is about 0.5 m^3 per kilogram of converted organics.

The sludge is separated from the main water stream by thickening. The sludge is recycled to the digester to maintain the organism concentration. The water with the remaining, more-difficult-to-ferment organics proceeds to the aerobic treatment step.

In the water treatment step, air is mixed with the wastewaters to degrade the remaining 15% of organics. The sludge formed is separated from the wastewater stream and recycled.

A sludge bleed can be removed from the plant and be used as a soil conditioner.

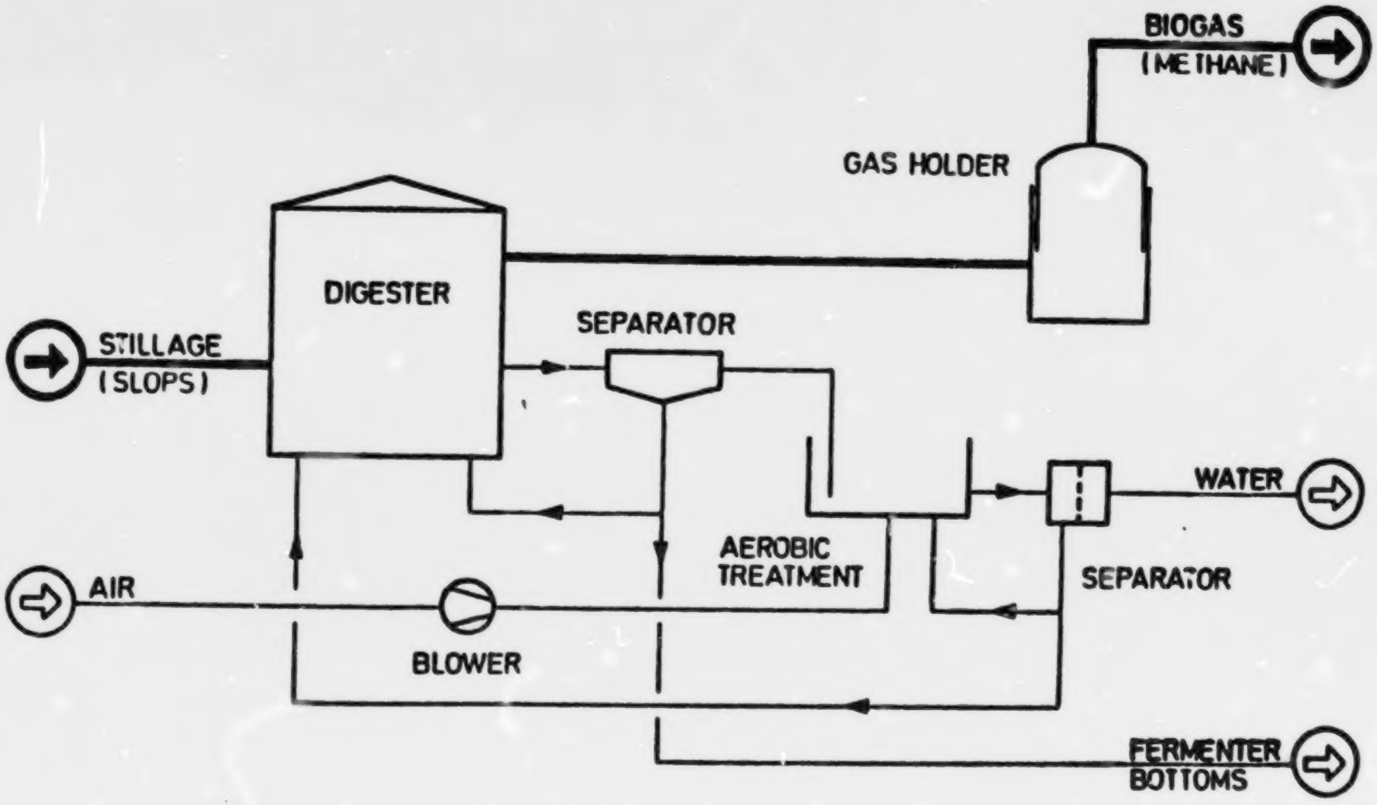

BIOGAS
(METHANE)
GAS HOLDER
DIGESTER
SEPARATOR
STILLAGE
(SLOPS)
WATER
AEROBIC
TREATMENT
AIR
SEPARATOR
BLOWER
FERMENTER
BOTTOMS

FIGURE 6-13 STILLAGE BIOGAS AND WATER TREATMENT

An alternative process for use of the stillage is conversion to high protein cattle fodder. For this case, additional natural gas would be needed by the plant to replace the biogas that would no longer be produced.

(iv) Balance of Plant

The utility system consists of the following main sections:

- cooling and process water supply;
- boiler water supply;
- steam and condensate handling;
- compressed and instrument air supply;
- electrical generation.

Cooling water circulates in a closed circuit. Warm cooling water from the process units passes first through a process heater where some of its heat content is used to warm up the water handled in the process water section. From the process water heater the cooling water passes to the main cooler where it gives up heat and is then returned to the process.

Raw water is supplied at the plant gate and is filtered to remove coarse impurities. The main user of process water is the hydrolysis section. However, most of this water can be recovered from the biogas plant.

Boiler feedwater is supplied to the steam boiler and the hydrolysis process.

The demineralized water is stored and blended with steam condensate recycled from the process units.

Plant steam requirements are split 50% for hydrolysis; 42% for distillation; and 8% for furfural recovery. The hydrolysis section needs 1,200 kPa steam, whereas the other sections use steam at lower pressure levels.

By-products from the plant available as fuels for steam production are:

- lignin (60% H_2O), higher heating value 9.6 MJ/kg;
- biogas, 66% CH_4 content, higher heating value 23 MJ/m^3.

This provides most of the boiler fuel requirement. A backup natural gas burner is also needed.

The principal power consumer is the solids handling plant for the wood raw material which uses about 30% of the total power requirement. The four main plant sections use roughly 10% each to a total of 44%. The balance goes to the by-product processing plants.

(c) Material and Energy Balances

(i) Material Balance

The material balance of the plant is sensitive to the yield of ethanol from wood. The Inventa process is claimed to yield 240 litres of 100% ethanol per dry tonne of softwood (Spruce). This is about 5 ODt wood/tonne ethanol. For hardwoods the ethanol yield is considerably lower at 180 L/t; equivalent to a wood requirement of 7 ODt/t ethanol).

These yields correspond to about 65% of theoretical cellulose to sugar conversion. This is a significant advance over the original Scholler process yields of 48%.

A mass balance was calculated based on published data (Mendelsohn and Wetstein, EMS-Inventa AG). This overall mass balance is shown in Table 6-3 on a per tonne of ethanol basis for softwoods.

Table 6-3

UNIT PRODUCTION MASS BALANCE FOR INVENTA PROCESS

Input	t/t EtoH	Output	t/t EtoH
Wood (O.D)	5.0	Ethanol (100%)	1.0
Sulphuric Acid (100%)	0.342	Calcium Sulphate	0.527
Limestone	0.411	Furfural	0.059
		Methanol	0.041

The wood requirement of 5 ODt wood per tonne of ethanol results in a feedstock requirement of 750 ODt/d for an ethanol output of 150 t/d. A mass balance for the major process components of the plant is summarized in Figure 6-14.

The ethanol yield from hog fuel which contains a significant amount of bark may be below the yield determined experimentally for white wood, though sufficient data are available to state what the yield of ethanol would be from feedstock containing bark.

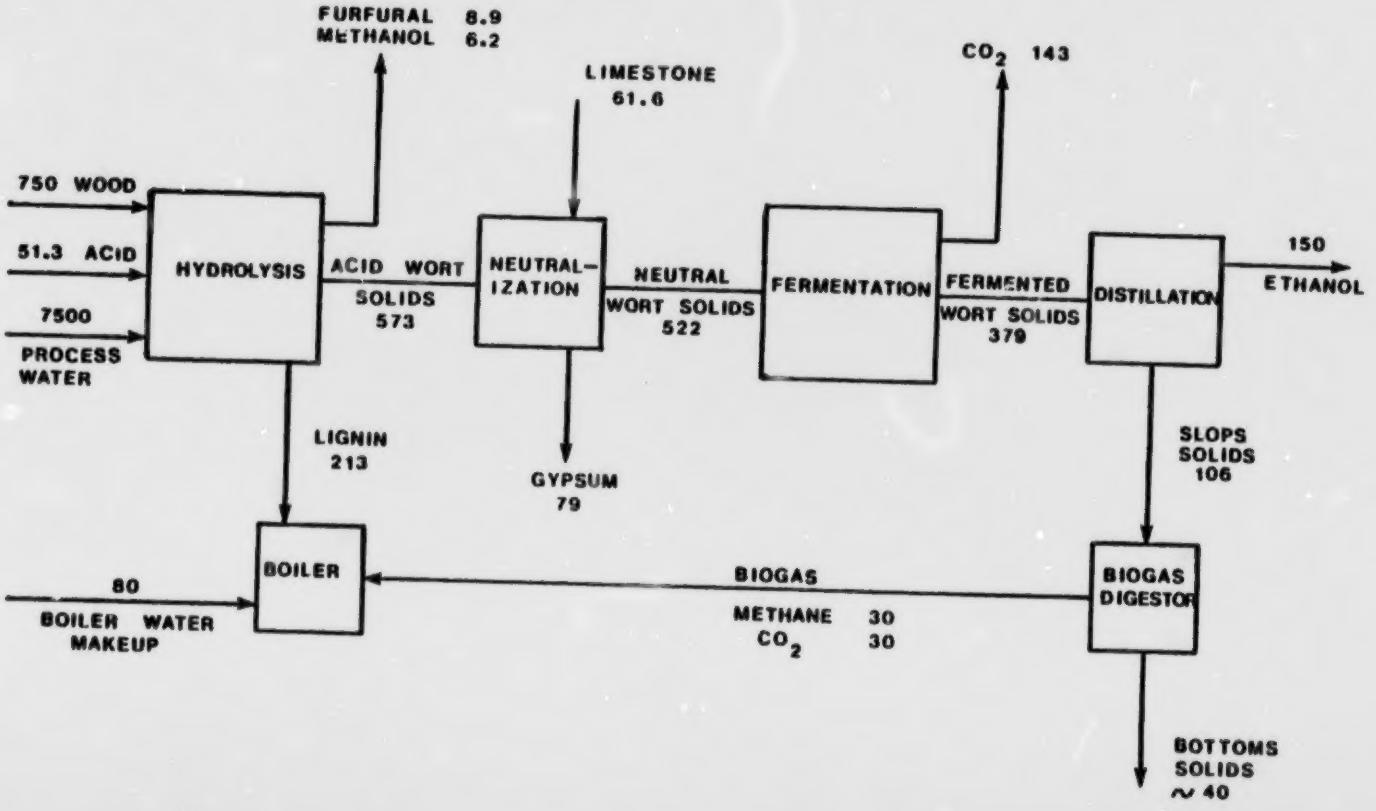
In the Madison process being developed by the New Zealand Forest Research Institute (Whitworth), bark is claimed to act as a deadload on the system, but does not interfere with fermentation. One explanation of the cause of the differing sensitivity of the two processes to bark is that Inventa uses a continuous process that is possibly easily disturbed by bark, while New Zealand Forest Research Institute uses a process that is less sensitive to such a disturbance.

(ii) Energy Balance

Producing ethanol from wood is energy intensive. It is characterized by high process heat demand and a relatively low electrical power demand, and thus, is very similar in terms of the magnitude and pattern of energy use to kraft pulping operations.

The total energy demand of the Inventa process is estimated to be 36 GJ/tonne of ethanol, this being about the same as the process heat requirement of kraft pulping. This is less than half of the energy required by the original Scholler process from which the Inventa process evolved.

A process heat flow diagram for the plant is shown in Figure 6-15, giving values for the lignin, wood, steam, and methane heating



FURFURAL 8.9
METHANOL 6.2
LIMESTONE
61.6
CO$_2$ 143
750 WOOD
51.3 ACID
7500
PROCESS
WATER
HYDROLYSIS
ACID WORT
SOLIDS
573
NEUTRAL-
IZATION
NEUTRAL
WORT SOLIDS
522
FERMENTATION
FERMENTED
WORT SOLIDS
379
DISTILLATION
150
ETHANOL
LIGNIN
213
GYPSUM
79
SLOPS
SOLIDS
106
80
BOILER WATER
MAKEUP
BOILER
BIOGAS
METHANE 30
CO$_2$ 30
BIOGAS
DIGESTOR
BOTTOMS
SOLIDS
~ 40

FIGURE 6-14 DAILY MASS FLOWS IN INVENTA PROCESS t/d

values on a daily basis. Based on the higher heating values of the wood and the ethanol, the thermal efficiency of the plant is 30%; significantly below the 47.5% efficiency for the methanol plant.

The plant is self-sufficient in energy by making full use of by-products for fuel. The lignin recovered from hydrolysis and the methane generated from the fermentor solids are burned in the boiler to supply 30 GJ/t ethanol of the 36 GJ/t ethanol required by the plant for process steam and heat. The actual energy available from the process by-products varies with the wood species, the bark content of the feedstock, and the efficiency of the biogas digester. The boiler is sized to generate 93,000 kg/h of steam on solid and gaseous fuels. The boiler is also equipped to burn natural gas as a backup fuel. If the fermentor solids are used for production of cattle fodder instead of biogas, then additional wood or natural gas would be needed for fueling the boiler.

The total energy requirement of the plant is 36 GJ/t ethanol, of which 27 GJ/t ethanol are used for distillation. This is relatively high for conventional multiple-effect distillation of fermentor product, but is caused, in this case, by the choice of a low ethanol content for this stream to maximize yield.

The electrical demand of the Inventa process is relatively low at about 600 kWh/t ethanol (near the demand of a kraft pulp mill). Plant electricity is co-generated with process steam.

(d) Capital and Operating Costs

The capital costs of the Inventa plant for producing 150 t/d of ethanol were based on published data given by Mendelsohn and Wetstein, and Pedco International Inc. and were updated to mid-1982 using the CE plant cost index. Exponents for adjustment of costs of plant components were obtained from Guthrie.

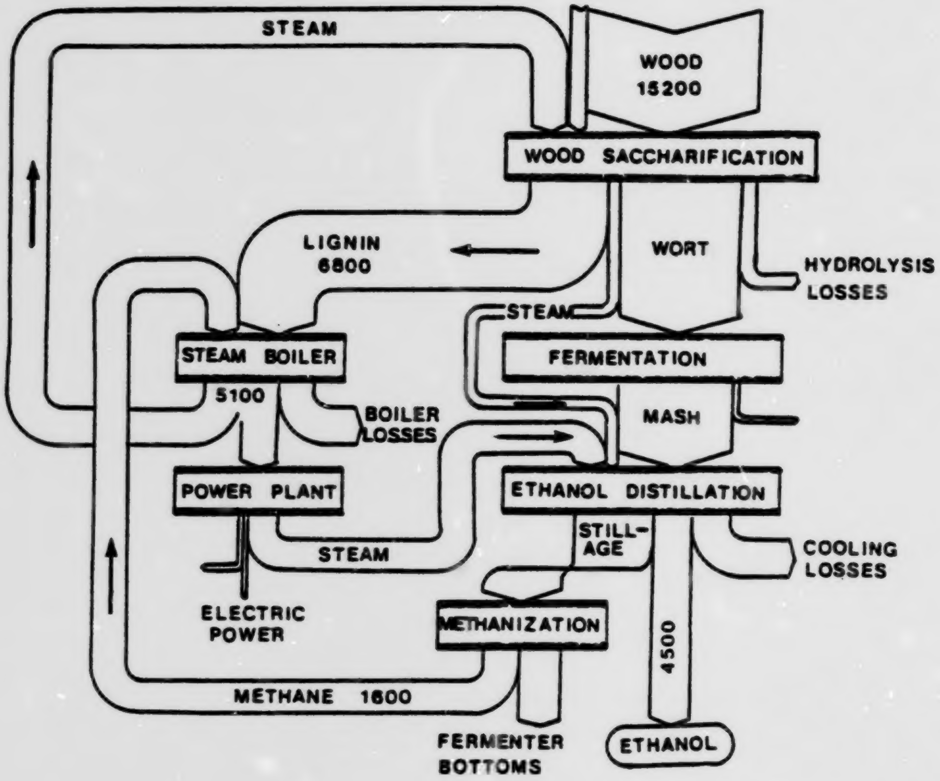

STEAM
WOOD
15200
WOOD SACCHARIFICATION
LIGNIN
6800
WORT
HYDROLYSIS
LOSSES
STEAM
STEAM BOILER
FERMENTATION
5100
BOILER
LOSSES
MASH
POWER PLANT
ETHANOL DISTILLATION
STILL-
AGE
COOLING
LOSSES
STEAM
ELECTRIC
POWER
METHANIZATION
4500
METHANE 1600
FERMENTER
BOTTOMS
ETHANOL

FIGURE 6-15 TOTAL ENERGY FLOWS IN INVENTA PROCESS (HEAT VALUES IN GJ/d)

A complete list of major plant equipment is given in Appendix B.

The total installed cost for a 150 t/d ethanol plant is $133.26 million when including by-product processing, and $89.27 million when excluding by-product processing. A breakdown of the costs by process area is given in Table 6-4.

The annual operating costs for the 150 t/d plant are $14.19 million with full by-product credits, and $15.64 million with no by-product credits. A breakdown of the operating costs, excluding those for feedstock and financing, are given in Table 6-5.

6.3 Capital and Operating Costs for a 300 t/d Ethanol Plant

Capital and operating costs do not vary linearly with plant size. As was done for the methanol plant, an ethanol plant of double the base case size was considered. The capital cost of this size plant was estimated using power factor relationships based on industrial experience.

The capital costs of process components of a 300 t/d ethanol plant are summarized in Table 6-6 with and without allowance for by-products.

Operating costs with and without by-product credits are summarized in Table 6-7.

6.4 Impact of Future Technological Improvements on Ethanol Production From Wood

Potential improvements in the technology for producing ethanol from wood can be classified into three areas:

- increased yield;
- decreased process energy requirements;
- decreased capital requirements.

Table 6-4

CAPITAL COSTS FOR A 150 t/d INVENTA ACID HYDROLYSIS ETHANOL PLANT WITH/WITHOUT BY-PRODUCT PROCESSING

Total Wood Feed (ODt/d)	750
Ethanol Production (t/d)	150

	($1,000)	
DIRECT AND INDIRECT CAPITAL COSTS:	With By-Products	Without By-Products
Wood Storage and Preparation	4,260	4,260
Hydrolysis	14,920	14,920
Neutralization	9,590	9,590
Fermentation	6,400	6,400
Distillation	8,530	8,530
By-Product Processing (Furfural)	35,180	---
Utilities and Off-sites	27,720	27,720
SUBTOTAL CAPITAL COSTS	106,600	71,420
Engineering Fee (10%)	10,660	7,140
Contingency (15%)	16,000	10,710
TOTAL INSTALLED COST (TIC)	133,260	89,270
Start-up Costs 5% TIC	6,660	4,460
Working Capital 2.5% TIC	3,330	2,230
	143,250	95,960

Table 6-5

OPERATING COSTS FOR A 150 t/d INVENTA ACID HYDROLYSIS ETHANOL PLANT WITH/WITHOUT BY-PRODUCT PROCESSING

				Annual Cost ($1,000)	
	Annual Quantity	Unit Price		With By-Product	Without By-Product
Utilities					
Electricity	1.5 X 10^6 kWh	2.5¢/kWh		38	38
Natural Gas	100,000 GJ/y	3.26 $/GJ		326	326
Water	2.7 X 10^6 kL	11¢/kL		297	297
			S/T	661	661
Labour					
Operating	60 men @ 2,080 h	$13.50/h		1,685	1,685
Maintenance	2.7% TIC			3,598	2,410
Supervision	20% (op & maint) labour			1,055	818
			S/T	6,338	4,913
Chemicals					
Sulphuric Acid	16,930 t	105 $/t		1,777	1,777
Limestone	20,325 t	25 $/t		508	508
			S/T	2,285	2,285
Supplies					
Maintenance	1.8% TIC			2,399	1,607
Operating	30% of op. labour			506	506
			S/T	2,905	2,113
Administration and General Overhead 70% Total Labour				4,437	3,439
Taxes and Insurance 2.5% of TIC				3,332	2,232
			S/T	7,769	5,671
TOTAL OPERATING COSTS				19,958	15,643
By-Product Credits					
Furfural	2,940 t/y	1,500 $/t		4,410	--
Methanol	2,045 t/y	280 $/t		573	--
Gypsum	26,100 t/y	30 $/t		783	--
			S/T	5,766	--
NET OPERATING COSTS				14,192	15,643

Table 6-6

CAPITAL COSTS FOR A 300 t/d INVENTA ACID HYDROLYSIS ETHANOL PLANT WITH/WITHOUT BY-PRODUCT PROCESSING

Total Wood Feed (ODt/d)	1,500
Ethanol Production (t/d)	300

	($1,000)	
DIRECT AND INDIRECT CAPITAL COSTS:	With By-Products	Without By-Products
Wood Storage and Preparation	6,460	6,460
Hydrolysis	22,620	22,620
Neutralization	14,540	14,540
Fermentation	9,700	9,700
Distillation	12,930	12,930
By-Product Processing (Furfural)	53,320	--
Utilities and Off-sites	42,010	42,010
SUBTOTAL CAPITAL COSTS	161,580	108,260
Engineering Fee (10%)	16,160	10,830
Contingency (15%)	24,240	16,240
TOTAL INSTALLED COST (TIC)	201,980	135,330
Start-up Costs 5% TIC	10,100	5,410
Working Capital 2.5% TIC	5,050	2,710
	217,130	143,450

Table 6-7

OPERATING COSTS FOR A 300 t/d INVENTA ACID HYDROLYSIS ETHANOL PLANT WITH/WITHOUT BY-PRODUCT PROCESSING

				Annual Cost ($1,000)	
	Annual Quantity	Unit Price		With By-Product	Without By-Product
Utilities					
Electricity	3×10^6 kWh	2.5¢/kWh		76	76
Natural Gas	200,000 GJ/y	3.26 $/GJ		652	652
Water	5.4×10^6 kL	11¢/kL		594	594
			S/T	1,322	1,322
Labour					
Operating	96 men @ 2,080 h	$13.50/h		2,696	2,696
Maintenance	2.7% TIC			5,453	3,654
Supervision	20% (op & maint) labour			1,630	1,270
			S/T	9,779	7,620
Chemicals					
Sulphuric Acid	33,860 t	105 $/t		3,554	3,554
Limestone	40,650 t	25 $/t		1,016	1,016
			S/T	4,570	4,570
Supplies					
Maintenance	1.8% TIC			3,636	2,690
Operating	30% of op. labour			809	809
			S/T	4,445	3,499
Administration and General Overhead 70% Total Labour				6,845	5,334
Taxes and Insurance 2.5% of TIC				5,050	3,383
			S/T	11,895	8,717
TOTAL OPERATING COSTS				32,011	25,728
By-Product Credits					
Furfural	5,880 t/y	1,500 $/t		8,820	--
Methanol	4,090 t/y	280 $/t		1,146	--
Gypsum	52,200 t/y	30 $/t		1,566	--
			S/T	11,532	--
NET OPERATING COSTS				20,479	25,728

Future improvements will be in all three major process areas: hydrolysis, fermentation, and ethanol separation.

(a) Hydrolysis

Improvements to hydrolysis processes would be to overcome the disadvantages of the two respective hydrolysis methods, acid or enzymatic, i.e.:

Acid hydrolysis disadvantages:

- low sugar yield (degradation);
- corrosion problems;
- high acid requirements;
- difficulty of acid recovery and disposal.

Enzymatic hydrolysis disadvantages:

- require extensive wood pretreatment;
- slow reaction rates;
- no commercial experience;
- sensitive to raw material characteristics.

The dilute sulphuric acid processes appear to be nearing their final phase of optimization (Inventa and New Zealand Forest Research Institute/Ultrasystems) at 65% sugar yield. Higher yields from acid hydrolysis may only be possible with strong acid processes such as the old Bergius hydrochloric acid process. The hydrochloric acid processes overcome the acid disposal problem common to dilute acid processes by incorporating acid recovery and recycling. Further development of the hydrochloric acid processes is continuing.

Enzymatic hydrolysis has the following advantages compared to acid hydrolysis:

- higher sugar yields (less degradation of sugars);
- simpler equipment (lower temperature and less corrosive process fluids);

- hemicelluloses are not degraded, leaving a potential for separate pentose fermentation and higher ethanol yield;
- compatible with fermentation (can hydrolyze and ferment simultaneously);
- lignin residues remain in active form and are therefore suitable for chemical uses.

In enzymatic hydrolysis, the progress from pilot scale to commercial application largely depends on advances in wood pretreatment technolgy. Pretreatments such as steam explosion appear to be commercially viable, but need to be demonstrated at a larger scale than done to date. The slow reaction rates that characterizes enzymatic hydrolysis may be improved by use of thermophilic enzymes. The raw material sensitivity is connected with both the pretreatment steps and the rate of reaction. Simultaneous hydrolysis and fermentation is attractive, but is yet at a very early stage of development.

Enzymatic hydrolysis enables pentose sugar separation and fermentation to augment ethanol production. The lignin residues from enzymatic hydrolysis are in the reactive form, and therefore, may be used as a feedstock for such things as production of phenols and glues. These products have higher values than the raw lignin that could be used only as boiler fuel. The energy self-sufficiency of the process would be reduced if chemical lignin is withdrawn, since additional wood or natural gas would be needed.

(b) Fermentation

Improvements to increase yield and decrease energy consumption and capital cost are expected for fermentation. The traditionally conservative beverage brewing technologies are giving way to more advanced industrial fermentation processes. Continuous fermentation processes have been developed in preferance to the traditional batch fermentation processes. These are more appropriate for commercial production of fuel-grade ethanol.

Fermentation of pentose sugars produced by hemicellulose hydrolysis promises to lead to a major increase in ethanol yield. The pentose sugars have to be fermented separately from the hexose sugars. Research to develop organisms for fermentation of pentose sugars and means of separation of these sugars after hydrolysis is presently underway.

(c) Ethanol Separation

The ethanol separation technologies are well developed and many choices are available to optimize energy use and capital costs. Presently, multiple-effect distillation systems and energy recovery networks, as exemplified by the Inventa design, appear to be state-of-the-art technology. The multi-column systems have a higher capital requirement than conventional distillation but lower energy needs. Use of vapour recompression distillation results in further energy reductions.

Several other separation technologies, such as extraction with liquid carbon dioxide, have the potential for a large energy reduction, but have no commercial experience.

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CHAPTER 7

ECONOMIC ANALYSIS

7.0 INTRODUCTION

Chapters 3 through 6 have developed wood supply costs and plant costs appropriate to various configurations of methanol and ethanol plants. This chapter will estimate the necessary plant gate prices of methanol and ethanol for each of the cases considered to pay for all operating costs and provide the necessary return to the debt and equity capital involved. These plant gate prices will then be compared to estimated refinery prices for gasoline over the forecast period to gauge the competitiveness of alcohol fuels in transportation applications. Retail pump price comparisons of gasoline to alcohol fuels will also be made; these will be very approximate being based only on cursory estimates of alcohol fuel distribution costs and of alcohol utilization costs in vehicles.

7.1 Plant Configurations

The plant sizes which are evaluated were largely determined based on the availability of wood feedstock at the Williams Lake and Kamloops sites. The cases which are analyzed are the following:

Plant Sizes Evaluated

Case 1	Product	Plant Size		Location
1.	ethanol	150 t/d	without by-product	Williams Lake
2.	ethanol	150 t/d	without by-product	Kamloops
3.	ethanol	300 t/d	with by-products	Williams Lake
4.	ethanol	300 t/d	without by-products	Williams Lake
5.	methanol	300 t/d		Williams Lake
6.	methanol	300 t/d		Kamloops
7.	methanol	600 t/d		Williams Lake
8.	methanol	990 t/d	wood/natural gas	Williams Lake

As may be noted, six of the eight cases are based on the Williams Lake site where the wood feedstock is cheaper and more plentiful. Two cases are considered at a Kamloops site to test the sensitivity of total production costs to the cost of feedstock. All other production and operating costs are considered equal at both locations.

7.2 Plant Capital and Operating Costs

Plant capital and operating costs, not including feedstock costs, which are detailed in Chapters 5 and 6, are summarized as follows:

Case #		Cap. Cost[a]	Op. Cost	Feedstock Requirement	
		(million 1982$)		Wood (000 ODt/yr)	N. Gas (PJ/yr)
1,2	150 t/d ethanol without by-products	96	16	248	---
3	300 t/d ethanol with by-products	217	20 [c]	495	---
4	300 t/d ethanol without by-products	143	26	495	---
5,6	300 t/d methanol	79	12	239	---
7	600 t/d methanol	124	20	478	---
8	990 t/d methanol	150 [b]	23	239	4.56

a. Including start-up costs and working capital.
b. Separate trains for gas and wood processors.
c. Includes credits for production of by-products.

7.3 Feedstock Costs

(a) Wood

Wood supply costs are detailed in Chapter 3. These costs are summarized as follows:

Site	Quantity and Cost
Williams Lake	300,000 ODt/yr @ $4/ODt* + 250,000 ODt/yr @ $14/ODt (from Quesnel)
Kamloops	350,000 ODt/yr @ $29/ODt

These wood supply costs, delivered to the plants, are calculated on the basis of transportation and handling costs only and do not include any allowance for avoidable disposal costs. Quantities of feedstock do not contain any chippable material; the Williams Lake quantities include bark plus other wood residues but the Kamloops volume includes bark only.

(b) Natural Gas

Natural gas costs for the hybrid natural gas/wood case are detailed in Appendix Table F-1a.

7.4 Economic Parameters

The economic parameters underlying the financial analyses of the eight plant cases above, such as debt/equity ratios, required return to capital, inflation rates, construction period, start-up schedule, etc., are detailed in Appendix F-1.

* One ODt = 20 GJ. $4/ODt is equivalent to $0.20/GJ.

7.5 Financial Analysis

The financial analyses conducted on the eight plant configurations are detailed in Appendix F-2. The plant gate prices for methanol and ethanol necessary to pay the required return to capital on these plants are summarized in Table 7-1.

7.6 Sensitivity Analysis

Sensitivity analyses are run on the 300 t/d ethanol plant (without by-product), the 600 t/d methanol plant, and the 990 t/d wood/natural gas plant all located at Williams Lake. The sensitivity cases which are tested are the following:

A. 25% increase in both capital and operating costs

B. 25% decrease in both capital and operating costs

C. alteration of debt/equity ratio to 100% equity

D. alteration of debt/equity ratio to 0% equity

E. increase in cost of debt and return on equity by 5% to 22% and 25% respectively

F. decrease in cost of debt and return on equity by 5% to 12% and 15% respectively

G. zero real escalation in both capital and operating costs

H. increase of 50% in cost of feedstock

I. decrease of 50% in cost of feedstock

The results of the sensitivity runs are summarized in Table 7-2. Though the sensitivity of the alcohol fuel price to variations in the wood feedstock cost is small at Williams Lake, reflecting the fact that woods costs at this price ($4/ODt) are only a small part of total costs, it is clear that wide swings in wood supply costs would be more important. This is illustrated by the difference of nearly 5¢/l in the breakeven

TABLE 7-1

BREAKEVEN PLANT PRICES FOR METHANOL AND ETHANOL

Case #	Product	Plant Size		(1) Required Plant Gate Price 1982 $/l
1	ethanol	150 t/d	William Lake	0.60
2	ethanol	150 t/d	Kamloops	0.70
3	ethanol with by-product	300 t/d	Williams Lake,	0.54
4	ethanol	300 t/d	Williams Lake	0.49
5	methanol	300 t/d	Williams Lake	0.24
6	methanol	300 t/d	Kamloops	0.29
7	methanol	600 t/d	Williams Lake	0.20
8	methanol	990 t/d	Williams Lake, natural gas/wood	0.20

SOURCE: Canadian Resourcecon Ltd.

(1) These are levellized prices. That is, they are constant over time in real dollar terms which give the required return to capital.

TABLE 7-2

SUMMARY OF SENSITIVITY ANALYSES

WILLIAMS LAKE LOCATION

	300 t/d Ethanol Without By-Product Unit Revenue 1982 ¢/l			600 t/d Methanol Unit Revenue 1982 ¢/l			990 t/d Methanol Unit Revenue 1982 ¢/l		
	Base Case	Sensitivity Case	Change	Base Case	Sensitivity Case	Change	Base Case	Sensitivity Case	% Change
A) 25% increase in K, O&M costs	48.6	60.0	+23.4	20.0	24.6	+23.0	19.9	23.2	+16.6
B) 25% decrease in K, O&M costs	48.6	37.2	-23.4	20.0	15.3	-23.5	19.9	16.5	-17.1
C) increase in equity from 50% to 100%	48.6	53.4	+9.4	20.0	22.1	+10.5	19.9	21.5	+8.0
D) decrease in equity from 50% to 0%	48.6	45.6	-6.2	20.0	18.7	-6.5	19.9	18.9	-5.0
E) increase in cost of debt & return on equity by 5%	48.6	54.8	+12.8	20.0	22.7	+13.5	19.9	21.7	+9.0
F) decrease in cost of debt & return on equity by 5%	48.6	43.3	-10.9	20.0	17.6	-12.0	19.9	18.3	-8.0
G) zero real K, O&M escalation	48.6	43.5	-10.5	20.0	18.0	-10.0	19.9	18.4	-7.5
H) 50% increase in feedstock cost	48.6	50.1	+3.1	20.0	20.7	+3.5	19.9	23.0	+15.6
I) 50% decrease in feedstock cost	48.6	47.1	-3.1	20.0	19.3	-3.5	19.9	17.0	-14.6

SOURCE: Canadian Resourcecon Ltd.

price of methanol in the 300 t/d plant case between the Williams Lake location ($4/ODt) and the Kamloops location ($29/ODt) (see Table 7-1).

7.7 British Columbia Gasoline Price Analysis

The following tables (Tables 7-3 and 7-4) develop the present and forecast refinery prices for regular grade unleaded gasoline in British Columbia.* The price forecasts are based on the principles established in the Canada/Alberta agreement relating to energy pricing and taxation dated Sept. 1, 1981. The principles set forth in that agreement with respect to such matters as the relationship of Canadian prices to world prices, the maintenance of a single Canadian price for oil, and the regulation of the relationship between natural gas and crude oil prices are assumed to continue after 1986 when the current agreement expires.

(a) Crude Oil Prices

The world price for crude oil to which the Canadian crude oil prices will be related is forecast to increase from its 1982 level of $45/Cdn./bbl. at an average real rate of 2 percent per year over the forecast period. A single Canadian oil price, varying only due to transportation or quality differentials, will be assumed to continue to prevail in all provinces, as it does today. This price will be approximately equal in Vancouver and Toronto. In 1982$ terms the British Columbia (Vancouver) price of crude oil is forecast to nearly double by 2000 to some $64/bbl. (Table 7-3).

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* A sensitivity case based on much lower crude oil and natural gas price forecasts is illustrated in Section 7.9

TABLE 7-3

FORECAST WEIGHTED AVERAGE CRUDE OIL PRICE, CANADA, 1982-2000

(1982 $)

	Old Oil		New Oil and Imported Oil		Weighted[5] Ave. Price Montreal	COA[6] Levy	Canadian Crude Oil Price	
	Qty.[1] (10^6bbls.)	Price[2] at Mtl. ($/bbl.)	Qty.[3] (10^6bbls.)	Price[4] at Mtl. ($/bbl.)	($/bbl.)	($/bbl.)	Montreal ($/bbl.)	Toronto[7] & Vancouver ($/bbl.)
July 1/								
1982	421	27.13	197	45.00	32.88	1.15	34.03	33.74
1983	385	32.00	222	45.90	37.02	2.00	39.02	38.73
1984	350	35.12	248	46.82	39.97	2.00	41.97	41.69
1985	315	35.81	274	47.75	41.36	2.00	43.36	43.09
1986	288	36.53	293	48.71	42.67	2.00	44.67	44.41
1987	261	37.26	312	49.68	44.02	2.00	46.02	45.77
1988	234	38.01	331	50.68	45.43	2.00	47.43	47.19
1989	207	38.77	350	51.69	46.89	2.00	48.89	48.66
1990	180	39.54	369	52.72	48.40	2.00	50.40	50.18
1995	116	43.66	442	58.21	55.19	2.00	57.19	57.01
2000	80	48.20	534	64.27	62.18	2.00	64.18	64.05

SOURCE: Canadian Resourcecon Ltd.

NOTES TO TABLE 7-3

(1) Old oil quantity is as estimated in the NEB report, Canadian Energy Supply and Demand 1980-2000, June 1981, for the "modified base case" (see p. 147).

(2) The "Old" oil price forecast is based on the Energy Pricing Agreement between the federal government and Alberta, dated September 1, 1981, whereby the maximum price at Montreal is specified at 75 percent of the price of international oil imported to Montreal.

An inflation rate of 10 percent per year is used for purposes of deflating "base prices" in the Energy Pricing Agreement to a 1982$ base.

(3) New and imported oil supply is the difference between total Canadian crude demand and old oil supply. Total Canadian demand for crude oil is as estimated by the NEB in their "low demand case" in the report Canadian Energy Supply and Demand, 1980-2000, June 1981.

(4) The "New" oil price forecast is based on the Energy Pricing Agreement (EPA) between the federal government and Alberta whereby the crude price at Montreal, adjusted for quality differences, is specified as 100 percent of the price of imported crude at Montreal, or the "base price" specified in the EPA, whichever is less. In all years from 1982 onwards the "New" price is calculated at 100 percent of the Montreal price (the EPA "base prices" from 1982 to 1986 are higher than this). The "New" oil price and the imported crude oil price are thus equal over the whole forecast period from 1982 to 2000.

The price at Montreal of imported crude in 1982, adjusted to Canadian crude quality standards, is estimated at $45.00/bbl. (1982$). The international crude price is forecast to increase at a real rate of 2 percent per year from this 1982 base. Gravity and sulfur adjustments are calculated to increase at the same rate as the price of the crude, i.e. at 2 percent per year (in 1982$).

(5) The Canadian crude oil price is the weighted average price of "Old" and "New" oil as follows:

$$\text{Cdn. Crude Price} = \frac{\text{"Old" Price x Old Supply + "New" Price x (New + Import Supply)}}{\text{Total Canadian Demand}}$$

Implicitly included in this Canadian price is the Petroleum Compensation Charge. The federal government pays all refiners of "New" and imported oil an allowance sufficient to reduce the price of this oil to the "Old" oil price. It then establishes the Petroleum Compensation Charge, which is levied on all oil refined in Canada, at a level sufficient to recover its payments to the refiners of "New" and imported oil. The result of adding the PCC to the "Old" oil price is a Canadian crude price equal to the weighted average price as described above.

NOTES TO TABLE 7-3 (CONTINUED)

(6) The "Canadianization" levy is arbitrarily increased to \$2.00/bbl. (1982\$) in 1983 and continued at that level for the remainder of the forecast period.

(7) The Canadian crude oil price at Toronto is less than the Montreal price by an amount equal to the IPL tariff from Toronto to Montreal. The IPL tariff is increased at a rate of 5 percent per year in current \$ terms; inflation is assumed at 10 percent per year so the tariff in 1982\$ decreases over the forecast period (from \$0.29/bbl. in 1982 to \$0.13/bbl. in 2000). The pipeline tariff from Edmonton to Toronto is forecast to be approximately equal to that from Edmonton to Vancouver so that Toronto and Vancouver city gate prices will be approximately equal.

TABLE 7-4

BRITISH COLUMBIA GASOLINE PRICE FORECAST AT THE REFINERY GATE 1982-2000

(1982$)

	Vancouver Crude Oil Prices		Crude Oil Price Increase From 1982	Regular Unleaded Gasoline Refinery Price	
July 1/	$/bbl.(1)	$/GJ(2)	$/bbl.	¢/1(3)	$/GJ*
1982	33.74	5.51	---	29.0	8.35
1983	38.73	6.33	4.99	32.7	9.42
1984	41.69	6.81	7.95	35.0	10.08
1985	43.09	7.04	9.35	36.0	10.37
1986	44.41	7.26	10.67	37.0	10.66
1987	45.77	7.48	12.03	38.0	10.95
1988	47.19	7.71	13.45	39.1	11.27
1989	48.66	7.95	14.92	40.2	11.59
1990	50.18	8.20	16.44	41.3	11.90
1995	57.01	9.32	23.27	46.5	13.40
2000	64.05	10.47	30.31	51.7	14.90

* 0.0347 GJ/1.

SOURCE: Canadian Resourcecon Ltd.

NOTES TO TABLE 7-4

(1) Source: Table 7-3.

(2) Crude oil energy conversion factor 6.12 GJ/bbl.

(3) The present refinery price of 29.0 ¢/l is estimated as follows, based on a current retail pump price for regular unleaded gasoline of 46.3 ¢/l:

	¢/l	
Refinery price	29.0	
Add: Federal sales tax @ 9%	2.6	
Wholesale dist. margin	3.0	
Dealer tank wagon	34.6	(industrial posted price)
Add: Gasoline excise tax	1.5	
Prov. road tax @ 20%	7.2	(20% x 36.1 ¢/l)
Retail dist. margin	3.0	(full serve)
Retail pump price	46.3	(reg. unleaded, full serve)

The forecoast gasoline price is increased by 0.75 ¢/l for every $1/bbl. increase in the price of crude oil (see the discussion in Section 7.7 b above).

(b) Gasoline Prices

Gasoline prices will increase due to the increased prices of the crude oil feedstock. All other costs such as refining and distribution costs are assumed to remain constant (in 1982$) over the forecast period. For every $1/bbl. increase in the cost of crude oil (2.86¢/gal.) the average price of all petroleum products is forecast to increase by 3.07¢/gal. to reflect a 7 percent loss in product due to own fuel use and losses in refining. Heavy fuel oil certainly, and possibly light fuel oil as well, will not be able to recover this incremental cost in full if these fuels are to stay competitive with future natural gas and electricity prices. As a result other products, including gasoline, must return more than the 3.07¢/gal. average if a refiner is to capture his increased costs. The price of gasoline at the refinery gate will therefore be forecast to increase at 3.5¢/gal. (0.75¢/l) for every $1/bbl. increase in the price of crude. The price at the retail pump will be further increased due to federal and provincial taxes which apply to the refinery price. The retail price will increase automatically by 9 percent of every refinery price increase due to the federal sales tax and the ad valorem British Columbia road tax will be assumed to continue at a rate of 20 percent of the retail price prior to the road tax being applied. The total retail gasoline price increase therefore, including taxes, for every $1/bbl. increase in the crude oil price, is calculated at 4.6¢/gal. (3.5¢ x 1.09 x 1.20) or approximately 1¢/l.

On the above basis the refinery price of regular grade unleaded gasoline in British Columbia is forecast to increase from 29¢/l currently to approximately 52¢/l in 2000 (Table 7-4).*

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* An alternative gasoline price for cost based on a lower crude oil price forecast is illustrated in Table 7-9.

7.8 Comparison of Prices for Gasoline, Methanol and Ethanol

Forecast plant gate prices for gasoline, methanol and ethanol have been developed above in Sections 7.6 and 7.7. Before comparing these to one another, several factors which will affect such end use comparisons need to be considered.

(a) Energy Efficiency

Energy contents of these fuels varies widely as follows:

	GJ/l
gasoline	0.0347
methanol	0.0180
ethanol	0.0232

Methanol has approximately 52 percent of the energy content of gasoline on a volumetric basis and ethanol approximately 67 percent.

(b) Octane Rating

The alcohols have higher octane ratings than gasoline as follows:

	Octane Rating R + M/2
gasoline	87-93
methanol	98-102
ethanol	99-102

As a result of this, alcohols can be more energy efficient fuels in spark ignition internal combustion engines if high compression engines are designed to take advantage of this characteristic. Estimates of 20 percent efficiency gain or more per unit of energy are postulated in vehicles designed for these fuels.

(c) Vehicle Modifications

Whether in blends or as straight fuels alcohols pose some problems to conventional engine technology with respect to corrosion, cold starting experience, odor, lubrication, and toxicity. Experience in the U.S. has shown most vehicles operate satisfactorily with 10 percent ethanol blends without engine modifications except that tuning adjustments may be required; with increasing concentrations engine modifications would be necessary. Methanol is more corrosive than ethanol; blends of 10 percent in gasoline will require vehicle component modifications primarily to avoid corrosion. The cost of modification would be significant compared to the volume of methanol used in such blends.

For straight alcohol fuels specially manufactured vehicles will have to be produced. Corrosion resistant materials will be mandatory, high compression engines will be necessary to take advantage of alcohols' high octane, and larger fuel tanks will be desirable to offset the lower volumetric fuel efficiency.*

(d) Fuel Distribution

In the U.S. ethanol has been successfully blended with gasoline in bulk, and distributed to service stations as a blend. It is generally considered feasible to blend the ethanol with gasoline at the refineries, if this proves desirable. Anhydrous ethanol is preferred to eliminate phase separation problems. At the service stations, "gasohol" generally is handled through storage and pumps previously used for premium unleaded. With this system, the distribution costs for ethanol will be approximately equal to gasoline per unit volume.

* A brief status report of the use of ethanol and methanol in motor vehicles is given in Appendix G.

Methanol/gasoline blends are more prone to phase separation than ethanol/gasoline blends at given concentrations. Small quantities of water and winter temperatures both increase the probability of phase separation. Methanol in significant concentrations (e.g., 10 percent) would have to be distributed separately with blending at the pump, to avoid water contamination and the attendant phase separation problems.

Distribution of straight alcohols will result in higher costs per unit energy delivered than for gasoline due to the higher volumes to be handled, but this cost increase should be less than in proportion to the energy content ratios of the fuels.

On a volume basis, the quantities of fuel grade methanol produced from a wood biomass plant will be small compared to total gasoline demands. Total consumption of gasoline in British Columbia in 1981 was 7,436 x 10^6 litres.* The output of methanol from the 990 t/d plants analyzed here would be some 413 x 10^6 l/yr; this is 5.5% of B.C.'s 1981 gasoline consumption on a volume basis, and 2.9% on an energy content basis.

(e) End Use Comparisons - Conclusions

The scope of this study does not enable a detailed investigation to be carried out of fuel utilization costs associated with alcohols in vehicle use or with fuel distribution costs from plant gate to retail locations; neither is time available to rigorously analyze engine technology and performance characteristics associated with the various fuel types. For purposes of this present analysis, it will be assumed that extra vehicle capital or conversion costs associated with alcohol fuels will balance the potential savings due to the higher energy conversion efficiencies associated with their use. As a result comparisons in this study will be made on the basis of the price per unit of energy associated with each fuel without further adjustment.

Refinery price comparisons made on this basis are shown in Table 7-5. (Alcohol levellized prices) and Table 7-5A (Alcohol prices at a constant percentage relationship to the gasoline price.)

*Statistics Canada 57-003.

TABLE 7-5

REFINERY GATE COMPARISONS OF GASOLINE, METHANOL AND ETHANOL

(1982$/GJ)

	Gasoline(1)	Methanol(2)		Ethanol(3)
		600 t/d	990 t/d	300 t/d
1986	10.66	11.11	11.06	20.94
1987	10.95	11.11	11.06	20.94
1988	11.27	11.11	11.06	20.94
1989	11.59	11.11	11.06	20.94
1990	11.90	11.11	11.06	20.94
1995	13.40	11.11	11.06	20.94
2000	14.90	11.11	11.06	20.94

(1) Source from Table 7-4.

(2) Source from Table 7-1 and a methanol conversion factor of 0.0180 GJ/l.

(3) Source from Table 7-1 and an ethanol conversion factor of 0.0232 GJ/l.

NOTE: For the alcohols, these are levellized prices which remain constant over time in real dollar terms and give the required return on investment.

TABLE 7-5A

REFINERY GATE COMPARISONS OF GASOLINE, METHANOL AND ETHANOL

HIGH GASOLINE PRICE FORECAST CASE

(1982$/GJ)

	Gasoline	Methanol		Ethanol
		600 t/d	990 t/d	300 t/d
1986	10.66	9.73	9.66	18.50
1987	10.95	10.00	9.92	19.00
1988	11.27	10.29	10.21	19.55
1989	11.59	10.58	10.50	20.10
1990	11.90	10.87	10.78	20.66
1991	12.18	11.13	11.04	21.16
1992	12.47	11.39	11.31	21.66
1993	12.76	11.66	11.57	22.16
1994	13.07	11.94	11.86	22.70
1995	13.40	12.23	12.14	23.25
1996	13.68	12.50	12.41	23.75
1997	13.97	12.76	12.67	24.25
1998	14.29	13.05	12.96	24.81
1999	14.58	13.32	13.22	25.31
2000	14.90	13.60	13.50	25.85

NOTE: For the alcohols, these are prices calculated at a constant percentage relationship to the gasoline price which give the required return on investment.

Retail prices for methanol and ethanol are developed in Table 7-6 and compared to forecast retail gasoline prices in Table 7-7. Ethanol and methanol prices are shown with and without federal and provincial fuel taxes. The estimated price of methanol is certainly attractive compared to gasoline even in the case where full fuel taxes are applied; without taxes its pump price is cheaper than gasoline from 1986 (the year in which the plant is commissioned) onward. Ethanol is calculated to be considerably more expensive than gasoline; its price is forecast to remain above the price of gasoline in both the with and without tax cases over the period to 2000.

TABLE 7-6

METHANOL AND ETHANOL RETAIL PRICES WITH AND WITHOUT TAXES

(1982$)

	Methanol		Ethanol	
	with taxes	w/o taxes	with taxes	w/o taxes
	¢/l		¢/l	
Refinery price	20.0	20.0	48.6	48.6
Federal sales tax @ 9%	1.8	---	4.4	---
Wholesale distribution margin(1)	4.5	4.5	4.5	4.5
Dealer price	26.5	24.5	57.5	53.1
Federal excise tax(2)	0.8	---	1.0	---
Provincial road tax(3)	2.8	---	7.8	---
Retail margin(4)	2.5	2.5	3.0	3.0
Retail pump price	32.4	27.0	69.3	56.1

SOURCE: Canadian Resourcecon Ltd.

(1) Wholesale distribution margin includes a 2¢/l cost for transportation from Williams Lake to Vancouver (Vancouver being the major market area) plus a 2.5¢/l distribution and marketing margin to final point of retail.

(2) The federal excise tax is calculated at the energy equivalent of the 1.5 ¢/l gasoline excise tax.

(3) The provincial road tax is calculated at a 20% ad valorum rate but then reduced in proportion to the energy content of a unit volume of the alcohol fuel compared to gasoline (e.g., for methanol 20% x 27.6 ¢/l x 0.52).

(4) Methanol retail margin based on a straight alcohol fuel system and compares to the gasoline of 3.0 ¢/l; the retail margin for methanol for a blended fuel based on separate methanol storage and blending would be higher at say 5.0 ¢/l of methanol. The ethanol retail margin is based on delivery of a blended fuel with gasoline; the retail margin would remain at 3.0 ¢/l of the blended fuel.

TABLE 7-7

RETAIL PUMP PRICE COMPARISON FOR GASOLINE, METHANOL AND ETHANOL

(1982 $)

	Gasoline(1)		600 t/d Methanol(2)				300 t/d Ethanol(3)			
			with tax		w/o tax		with tax		w/o tax	
	¢/l	$/GJ	¢/l	$/GJ	¢/l	$/GJ	¢/l	$/GJ	¢/l	$/GJ
1982	46.3	13.34	32.4	18.00	27.0	15.00	69.3	29.87	56.1	24.18
1983	51.3	14.78	32.4	18.00	27.0	15.00	69.3	29.87	56.1	24.18
1984	54.3	15.65	32.4	18.00	27.0	15.00	69.3	29.87	56.1	24.18
1985	55.7	16.05	32.4	18.00	27.0	15.00	69.3	29.87	56.1	24.18
1990	62.7	18.07	32.4	18.00	27.0	15.00	69.3	29.87	56.1	24.18
1995	69.6	20.06	32.4	18.00	27.0	15.00	69.3	29.87	56.1	24.18
2000	76.6	22.07	32.4	18.00	27.0	15.00	69.3	29.87	56.1	24.18

(1) Gasoline retail pump price increased from September 1982 base at 1¢/l for every $1/bbl. increase in the price of crude oil.

(2) Source: Table 7-6.

(3) Source: Table 7-6.

7.9 Sensitivity Case Based on Lower Crude Oil, Gasoline and Natural Gas Price Forecasts

Most oil industry analysts presently tend to the view that world oil prices will decline in real terms to the mid or late '80's, and remain stable or increase only slowly beyond that time. This present view is based on the belief that world demand will be permanently lower than previously thought due to large and permanent price induced conservation measures, substitution away from oil to other energy forms, and perhaps permanently lower rates of world economic activity. On the supply side, it is believed probable that crude oil supplies, both inside and outside OPEC countries, are much greater than previously perceived.

Until very recently, say to the end of 1981, a similar majority view of industry planners held the quite different view that the long term trend of crude oil prices was likely to be upwards in real terms. The supporting analysis felt that world oil suppliers would be hard pressed to satisfy the every increasing world demands, and that hence real prices must increase. In other words, continually increasing world demands, taken together with the upward sloping supply curve for oil, would lead to ever increasing equilibrium prices.

The question that is posed is whether fundamental changes have occurred in underlying crude oil supply and demand relationships, and in world economic prospects, to justify the belief that current forecasts are more soundly based than the previous ones; or is the fact that present forecasts differ so markedly from earlier ones a reflection of the fact that predictions of future events are overly influenced by prevailing conditions at the time the forecasts are made: forecasts made in bull markets tend to be bullish, while those made in bear markets are likely to be bearish.

This is a difficult question to assess. Sound arguments can be marshalled to support either scenario. Though most present price forecasts favor low rather than high future prices, our view is that either outcome is a reasonable possibility. Because a great deal of uncertainty does surround future crude oil prices (based in good part on the extreme volatility in prices that have existed since 1973), sound analysis would dictate that a range of prices be considered to the year 2000 when evaluating the economics of alternative fuel projects.

A low boundary of the future probably crude oil price range will thus be forecast for sensitivity analysis purposes, as shown in Table 7-8. This forecast sees the price of world crude declining in current dollars by 10% in 1983, and then remaining at that level through 1985; from 1985 to 1990 the price will increase at the inflation rate, and from 1990 to 2000 at a rate of 1% per year faster than the inflation rate.

The lower crude oil price forecast, as detailed in Table 7-8, results in a much lower gasoline price forecast than in the base case analysis. The base case forecast (Table 7-4) resulted in a gasoline price by 2000 of nearly $15/GJ. The gasoline price forecast based on the low crude oil price case shows a price in 2000 of only $8/GJ (Table 7-9).

The natural gas price forecast is substantially reduced in the low crude oil price case based on the assumed price relationship between these two energy forms. The large industrial natural gas price is forecast to increase to $3.91/GJ in 2000 (Table 7-10) compared to the base case forecast of $7.31/GJ (Appendix Table F-1a).

Refinery gate comparisons of gasoline and methanol are shown in Table 7-11 for the low crude oil price case. The refinery gate price of methanol produced from the 600 t/d plant (Case #7) is now appreciably

TABLE 7-8

CRUDE OIL PRICE FORECAST(1)

LOW CASE

($/bbl.)

	World Crude Oil Price		Canadian Crude Oil Price	
July,	Current(2) $	1982 $	Current(4) $	1982 $
1982	43.00(3)	43.00	33.74	33.74
1983	38.70	35.18	34.82	31.65
1984	38.70	31.98	38.70	31.98
1985	38.70	29.08	38.70	29.08
1986	42.57	29.08	42.57	29.08
1987	46.83	29.08	46.83	29.08
1988	51.51	29.08	51.51	29.08
1989	56.66	29.08	56.66	29.08
1990	62.33	29.08	62.33	29.08
1995	105.03	30.56	105.03	30.56
2000	161.67	32.12	161.67	32.12

SOURCE: Canadian Resourcecon Ltd.

(1) Rate of inflation remains constant at 10% per year over the forecast period. Exchange rate remains constant at $0.80 U.S. = $1.00 Cdn.

(2) Current dollar price of world crude declines 10% in 1983, remains constant through 1985, increases at the rate of inflation 1985 to 1990, and increases at rate 1% greater than inflation from 1990 to 2000.

(3) The 1982 price of crude oil imported to Montreal averaged approximately $32.50/bbl. U.S. for average crude quality of 30°API and 1.25% S. This is equivalent to a price of $43 Cdn./bbl. adjusted to Canadian quality (38°API and 0.5% S), using an exchange rate of $0.80 U.S. = $1.00 Cdn.

(4) Canadian crude oil price increases to 90% of world price in 1983, to 100% of world price in 1984, and remains at 100% of world for remainder of forecast period.

TABLE 7-9

BRITISH COLUMBIA GASOLINE PRICE FORECAST AT THE REFINERY GATES 1982-2000

LOW PRICE FORECAST

(1982 $)

	Vancouver Crude Oil Prices[1]		Crude Oil Price Increase From 1982	Regular Unleaded Gasoline Refinery Price[2]	
	$/bbl.	$/GJ	$/bbl.	¢/l	$/GJ
1982	33.74	5.51		29.0	8.35
1983	31.65	5.17	-2.09	27.4	7.90
1980	31.98	5.23	-1.76	27.7	7.98
1985	29.08	4.75	-4.66	25.5	7.35
1986	29.08	4.75	-4.66	25.5	7.35
1987	29.08	4.75	-4.66	25.5	7.35
1988	29.08	4.75	-4.66	25.5	7.35
1989	29.08	4.75	-4.66	25.5	7.35
1990	29.08	4.75	-4.66	25.5	7.35
1995	30.56	4.99	-3.18	26.6	7.67
2000	32.12	5.25	-1.62	27.8	8.01

SOURCE: Canadian Resourcecon Ltd.

(1) From Table 7-8.

(2) The forecast gasoline price at the refinery gate is decreased by 0.75¢/l for every $1/bbl. decline in the price of crude from the 1982 level.

TABLE 7-10

NATURAL GAS PRICE FORECAST

LOW CASE

(1982$/GJ)

	B.C.(1) City-Gate Price	Large(2) Industrial Price
1982	2.76	3.26
1983	2.89	3.09
1984	2.62	3.12
1985	2.38	2.88
1986	1.47	2.97
1987	2.57	3.07
1988	2.66	3.16
1989	2.76	3.26
1990	2.85	3.35
1995	3.24	3.74
2000	3.41	3.91

SOURCE: Canadian Resourcecon Ltd.

(1) B.C. city-gate price is 50% of Canadian crude oil price (Table 7-9) to 1985, increases at 2% per year to 60% by 1990, increases at 1% per year to 65% by 1995, and remains at 65% thereafter.

(2) The large industrial customer price is 50¢/GJ higher than the city-gate price.

TABLE 7-11

REFINERY GATE COMPARISONS OF GASOLINE AND METHANOL PRICES 1986 - 2000

LOW CRUDE OIL AND NATURAL GAS PRICE FORECAST CASE

(1982$/GJ)

	Gasoline(1)	Methanol	
		600 t/d(2)	990 t/d(3)
1986	7.35	11.10	9.45
1987	7.35	11.10	9.45
1988	7.35	11.10	9.45
1989	7.35	11.10	9.45
1990	7.35	11.10	9.45
1995	7.67	11.10	9.45
2000	8.01	11.10	9.45

SOURCE: Canadian Resourcecon Ltd.

(1) Gasoline price forecast from Table 7-9.

(2) Based on Case #7 financial analysis (Appendix F-2) and methanol conversion factor of 0.0180 GJ/l.

(3) Based on Case #9 financial analysis (Appendix F-2) and methanol conversion factor of 0.0180 GJ/l.

NOTE: For methanol, these are levellized prices which remain constant over time in real dollar terms and give the required return on investment.

higher than the forecast gasoline price. The 990 t/d wood/natural gas plant (Case #9) produces methanol at a price of $9.45/GJ compared to $11.06/GJ in the base case analysis (Table 7-5) due to the much lower natural gas feedstock cost; this fuel price is still, however, above the forecast gasoline price of $7.35/GJ to $8.01/GJ.

The retail pump price comparison of gasoline and methanol shows gasoline to be the lowest priced fuel over the whole period 1986 to 2000 (Table 7-12); methanol without provincial road taxes or federal taxes is quite close to the gasoline price, however.

TABLE 7-12

RETAIL PUMP PRICE COMPARISON FOR GASOLINE AND METHANOL

(1982 $)

	Gasoline[1]		Methanol[2] 600 t/d Plant		Methanol[3] 990 t/d Plant	
	¢/l	$/GJ	$/GJ		$/GJ	
			With Tax	Without Tax	With Tax	Without Tax
1986	41.6	11.99	18.00	15.00	16.00	13.33
1987	41.6	11.99	18.00	15.00	16.00	13.33
1988	41.6	11.99	18.00	15.00	16.00	13.33
1989	41.6	11.99	18.00	15.00	16.00	13.33
1990	41.6	11.99	18.00	15.00	16.00	13.33
1995	43.1	12.42	18.00	15.00	16.00	13.33
2000	44.7	12.88	18.00	15.00	16.00	13.33

(1) Gasoline retail pump price of 46.3¢/l in 1982 (Table 7-7), adjusted by 1.0¢/l for every $1/bbl. change in the crude oil price. Gasoline energy content is 0.0347 GJ/l.

(2) Based on a refinery price of 20¢/l (see Tables 7-6 and 7-7).

(3) Based on a refinery price of 17¢/l, retail pump price with taxes of 28.8¢/l and without taxes 24.0¢/l (calculated as per Table 7-6).

NOTE: For methanol, these are levellized prices which remain constant over time in real dollar terms and give the required return on capital.

APPENDICES

APPENDIX A

LIST OF INTERVIEWEES FOR CHAPTER 3

APPENDIX A

LIST OF INTERVIEWEES FOR CHAPTER 3

Name	Affiliation	Location
Mr. V. Holm	B.C. Ministry of Forests	Victoria
Mr. D. Bryan	Council of Forest Industries	Vancouver
Mr. D. MacDonald	B.C. Ministry of Forests	Williams Lake
Mr. B. Jenkins	B.C. Ministry of Forests	Williams Lake
Mr. A. Coombes	Weldwood of Canada	Williams Lake
Mr. A. Dalgleish	Cariboo Pulp & Paper	Quesnel
Mr. B. Bush	Cariboo Pulp & Paper	Quesnel
Mr. J. Betts	Quesnel Waste Disposal	Quesnel
Mr. A. Stephens	B.C. Ministry of Environment	Williams Lake
Mr. T. Robinson	B.C. Ministry of Forests	Kamloops
Mr. M. Wilkins	B.C. Ministry of Forests	Kamloops
Mr. S. Tolnai	Weyerhaeuser Canada	Kamloops
Mr. L. Clay	Weyerhaeuser Canada	Kamloops
Mr. D. Munro	Weyerhaeuser Canada	Kamloops
Mr. A. Sinclair	Forest Engineering Research Institute of Canada (FERIC)	Vancouwer
Mr. J. Blakeney	Forestal International Ltd.	Vancouwer
Mr. S. Tiechy	B.C. Forest Products	Vancouwer
Mr. B. Bonus	Canadian Forest Products	Vancouwer

APPENDIX B

A STUDY OF THE BASIS FOR COMPARING THE ECONOMICS OF NATURAL GAS AND WOOD FUELS IN THE FOREST PRODUCTS INDUSTRY

APPENDIX B

B.H. Levelton - A Study of the Basis for Comparing the Economics of Natural Gas and Wood Fuels in the Forest Products Industry. Prepared for Inland Natural Gas Co. Ltd., Vancouver, B.C. 1981.

EXECUTIVE SUMMARY

The study has identified four types of wood burning equipment that can be used by the forest products industry to supplant natural gas. The types of equipment are suspension burners, fluidized bed combustors, multiple chamber combustors, and packaged steam boilers. Systems in the four categories have different fuel requirements (size and moisture content), provide the energy in different forms (hot gas, hot oil, or steam) and have differing advantages and disadvantages. These different characteristics are summarized in Table 1.

Five manufacturers have been selected representing the four categories of wood burning systems. These systems have been applied to three typical size sawmills; a small mill with an annual production of 25 million fbm, a medium mill with an annual production of 50 milion fbm, and a large mill with an annual production of 100 million fbm. A total of 11 case studies have been developed for the five manufacturers and the three sizes of mills.

Three scenarios of gas prices for the next 15 years have been developed. The first scenario (A) allows for most of the currently identified price increases for the next three years and then about an 8% increase a year after that. The second scenario allows for only the federal tax on gas to be passed on until 1983 after which prices rise at 8% a year. The third scenario falls between the first two, $0.50/MCF is added in the first year as well as the increase in federal taxes. After 1983 the gas prices are increased at 8% a year.

For each of the 11 cases and three gas price scenarios the economics of the proposed system have been worked out using an after tax discounted cash flow method to determine the internal rate of return. The payback period has also been calculated for each case.

The analyses indicate several factors:

1. There are economies of scale involved. The larger systems provide better returns on investments.
2. The systems that are designed to burn dry fuel (packaged boilers and suspension burner), provide the highest return on investment.
3. If all of the presently identified potential gas price increases occur (gas price Scenario A), most of the systems studied will be economically attractive to mill owners.
4. If the present gas price is ajusted for inflation (gas price Scenario B) then only one or two of the systems studied would be economically attractive to mill owners.

TABLE B-1 - SUMMARY OF WOOD-FIRED COMBUSTION SYSTEMS CHARACTERISTICS

	Suspension Burners	Fluid Bed Combustors	Multiple Chamber Combustors	Packaged Boilers
Manufacturers	Energex, Coen, Peabody Gordon-Piatt, Guaranty Performance, McConnell, Georgia Pacific, Bumstead-Woolford	Energy Products of Idaho, Incinergy, Applied Combustion Systems, Thermal Process, Combustion Power, Dectak, Dorr-Oliver, Johnston Boiler	Konus-Kessel, Anga & Varme, Lamb, Berg and Starck, Withermo	Mottpac Boilers (Vekos), Volcano, Vyncke
Fuel Requirements	Dry and fine	Wet hog fuel	Wet Hog fuel	Dry shavings
Energy output	Hot gas with some ash	Hot gas with some ash	Hot gas with very little ash or hot oil	Steam (low pressure)
Advantages	-Relatively inexpensive -Simple systems	Will burn wet hog fuel	-Will burn wet hog fuel -Versatility of hot oil systems -Can be used for space heating	-Relatively inexpensive -No contamination by ash -Can be used for space heating
Disadvantages	-Requires dry, fine fuel -Particulate in hot gas causes some contamination in drying process -Some require supplemental fuel	-Limited turndown -Particulate in hot gas causes some contamination in drying process	Hot oil systems are expensive	-Effectively limited to 10 million Btu/hour by government legislation -Requires dry fuel
Typical Return Ranges of Internal Rates of Return with Gas Price Scenario A	25 - 35%	20 - 25%	5 - 30%	25 - 30%

APPENDIX C

MILL RESIDUALS TRANSPORTATION COSTS

APPENDIX C

MILL RESIDUALS TRANSPORTATION COSTS

Background

Cariboo Pulp and Paper in Quesnel and Weyerhauser Canada in Kamloops are the two major purchasers of hog fuel and pulp chips in the study areas. Both firms contract for pulp chip and hog fuel delivery with Arrow Transfer Ltd. Hog fuel transportation in the Quesnel area is predominantly a very short haul, with the collection of residuals from mills in the Two Mile flat area for delivery across the river to the pulp mill. The round trip for this short haul is approximately four miles. In contrast, hog fuel transportation in the Kamloops area involves more varied and significantly longer truck hauls, the longest being from Westbank, 120 miles from the Kamloops mill.[1] Hog fuel transportation cost estimates for both short and long haul are therefore based on the actual cost experience of the two contracting mills.

Transportation Units

Different types of vehicles are used for long distance hauling of wood chips in the Cariboo region and for hauling wood chips and mill residuals in the Kamloops region. For prospective longer haul shipments of hog fuel in the Cariboo area, costs similar to those currently incurred in the shipment of wood chips are considered applicable. For wood chip shipments in the Cariboo region, a seven axle truck unit called a "B-train" is used. The B-train has a gross vehicle weight rating of 125,000 lbs., and can carry an 80,000 lb. payload. In the Kamloops region, a six-axle truck unit called a "truck-n-pup" is used for transporting wood chips and hog fuel. The truck-n-pup has a GVW rating of 100,000 lbs, and a payload of 65,000 lbs.

Cost Estimates

In Quesnel, current short haul hog fuel transportation costs incurred by

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(1) Weyerhaeuser Canada Ltd., pers. comm.

Cariboo Pulp & Paper are approximately $4.00 per ODt for shipments from the Two-Mile flat area. This is considered a minimum cost for hauling hog fuel and reflects mostly loading and unloading time rather than a mileage cost associated with haul distance.

For hauling mill residuals from Quesnel to Williams Lake, a cost estimate has been derived assuming a B-train is used with a cost of $300 per trip, or roughly $14.00 per ODt.[1]

In the Kamloops area, current hog fuel transportation costs incurred by Weyerhauser are approximately .25/km/BDU,[2] subject to a minimum $5.00/BDU for transportation distances under 20 km. On this basis, hog fuel transportation costs by source of supply are shown below in Table 1.

TABLE C-1

Origin	Distance from Kamloops (km)	Available Bark Surplus Volume ('000 ODt)	Marginal Transport Cost ('000 ODt)	Cumulative Transport Cost ($'000)	Average Transport Cost per ODt
Kamloops area	---	55	5.00	275	5.00
Savona	40	15	10.00	425	6.07
Louis Creek	58	7	14.50	527	6.84
Barriere	62	11	15.50	698	7.92
Merritt	93	40	23.25	1,628	12.71
Adams Lake	115	20	28.75	2,203	14.88
Clearwater/Canoe	120	73	30.00	4,393	19.87
Vavenby	150	70	37.50	7,018	24.11
Armstrong	175	15	43.75	7,674	25.08
Lavington	185	44	46.25	9,709	27.74
Lumby	200	18	50.00	10,609	28.83

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(1) Cariboo Pulp & Paper, pers. comm.

(2) Weyerhaeuser Canada, pers. comm.

APPENDIX D

MATERIAL AND ENERGY BALANCE SHEET FOR A 300 t/d METHANOL PLANT

Table D-1

MATERIAL AND ENERGY BALANCE SHEET

Stream Number		1		2		3		4		5	
Description		Wood to Storage		Wood From Feed Preparation		Wood to Boiler		Wood to Gasifier		Char and Ash From Gasifier	
Component	mol wt	mol/h	kg/h	mol/h	kg/h	mol/h	kg/h	mol/h	kg/h	mol/h	kg/h
Biomass			30,165		30,165		5,165		25,000		
Char											1,500
Catalyst											1,750
Ash											300
Tars and Oils											
Carbon Monoxide	28.01										
Carbon Dioxide	44.01										
Hydrogen	2.01										
Methane	16.04										
Ethane	30.07										
Water	18.02		24,725		24,725		4,225		20,500		
Methanol	32.04										
Total			54,890		54,890		9,390		45,500		3,550
HHV and Sensible Heat (GJ/h) (Ref:25°C)		595.3		595.3		101.8		493.5		36.0	
Pressure (kPa)		101		101		101		101		101	
Temperature (°C)		15		15		15		15		540	

Table D-1 (continued)

MATERIAL AND ENERGY BALANCE SHEET

Stream Number		6		7		8		9		10	
Description		Catalyst to Gasifier		Syntnesis Gas From Gasifier		Waste Water From Cleanup		Synthesis Gas to Reformer		Synthesis Gas For Fuel	
Component	mol wt	mol/h	kg/h	mol/h	kg/h	mol/h	kg/h	mol/h	kg/h	mol/h	kg/h
Biomass											
Char											
Catalyst			1,750								
Ash							250				
Tars and Oils											
Carbon Monoxide	28.01			59,468	1,666			59,681	1,672	16,914	474
Carbon Dioxide	44.01			491,598	21,635			490,204	21,574	138,923	6,114
Hydrogen	2.01			335,000	677			334,744	676	94,866	192
Methane	16.04			263,639	4,229			262,910	4,217	74,509	1,195
Ethane	30.07			47,574	1,431			47,889	1,440	13,572	408
Water	18.02			784,971	14,145		13,875	6,858	124	1,944	35
Methanol	32.04										
Total			1,750	1,982,250	43,783		14,125	1,202,286	29,703	340,728	8,418
HHV and Sensible Heat (GJ/h) (Ref:25°C)				472.5		23.6		422.8		119.8	
Pressure (kPa)		101		1,144		101		1,144		450	
Temperature (°C)		15		250		38		38		38	

Table D-1 (continued)

MATERIAL AND ENERGY BALANCE SHEET

Stream Number		11		12		13		14		15	
Description		Purge Gas From Synthesis		Steam to Reformer		Synthesis Gas to Acid Removal		CO2 Vent		Steam to Acid Gas Removal	
Component	mol wt	mol/h	kg/h	mol/h	kg/h	mol/h	kg/h	mol/h	kg/h	mol/h	kg/h
Biomass											
Char											
Catalyst											
Ash											
Tars and Oils											
Carbon Monoxide	28.01	17,135	480			352,600	9,876				
Carbon Dioxide	44.01	14,260	628			285,520	12,566	182,202	8,063		
Hydrogen	2.01	7,760	145			909,880	1,838				
Methane	16.04	11,040	177			12,040	193				
Ethane	30.07										
Water	18.02	115	2	931,250	16,781	158,928	2,864	62,048	1,118	522,500	9,415
Methanol	32.04	736				516	17				
Total		115,046	1,432	931,250	16,781	1,719,484	27,354	245,250	9,181	522,500	9,415
HHV and Sensible Heat (GJ/h) (Ref:25°C)		35.8		52.8		381.3		0.5		25.3	
Pressure (kPa)		450		1,144		865		101		1,140	
Temperature (°C)		38		400		93		66		185	

Table D-1 (continued)

MATERIAL AND ENERGY BALANCE SHEET

Stream Number		16		17		18		19		20	
Description		Synthesis Gas to Compression		Synthesis Gas to Converter		Purge Gas		Methanol to Distillation		Methanol to Storage	
Component	mol wt	mol/h	kg/h	mol/h	kg/h	mol/h	kg/h	mol/h	kg/h	mol/h	kg/h
Biomass											
Char											
Catalyst											
Ash											
Tars and Oils											
Carbon Monoxide	28.01	353,100	9,890	352,640	9,877	17,135	480	968	27		
Carbon Dioxide	44.01	102,300	4,502	103,313	4,547	14,260	628	32,411	1,426		
Hydrogen	2.01	910,800	1,840	909,150	1,836	71,760	145	2,419	5		
Methane	16.04	11,550	185	11,020	177	11,040	177	339	5		
Ethane	30.07	165	5								
Water	18.02	273,075	4,921	1,791	32	115	2	57,566	1,037	1,958	35
Methanol	32.04	330	11	551		736	24	389,661	12,485	389,661	12,485
Total		1,651,320	21,354	1,378,465	16,469	115,046	1,456	483,364	14,985	391,619	12,520
HHV and Sensible Heat (GJ/h) (Ref:25°C)		377		371		35.8		284.8		283.3	
Pressure (kPa)		865		5,050		5,050		101		101	
Temperature (°C)		110		38		38		38		20	

APPENDIX E

MAJOR EQUIPMENT LIST OF INVENTA PROCESS

Table E-1

MAJOR EQUIPMENT LIST OF INVENTA PROCESS

Equipment
Wood storage and conveying equipment
Wood screening
Acid storage and handling
Limestone storage and handling
Hydrolysis batch reactors
Wort flash system
Flash/process water preheater
Furfural collection
Neutralization reactor
Centrifuge
Gypsum by-product storage
Wort conditioning
Neutral wort flash system
Flash/process water preheater
Final clarifier
Fermentation reactor series (line 1)
Fermentation reactor series (line 2)
Off-gas cleaner and blower
Yeast separator
Yeast wash system
Rectifier column 1
Feed preheater
Reflux condensor (column 1)
Rectifier column 2
Reflux condensor (column 2)
Azeotrope column
Reflux condensor (azeotrope column)
Entrainer decanter
Entrainer stripping column
Condensor (stripping column)
Fusel oil extractive column
Fusel oil concentrating tower column
Lignin dewatering
Boiler
Boiler water treatment
Steam turbine generator
Slops digestor
Waste water treatment

APPENDIX F

FINANCIAL ANALYSIS

APPENDIX F - FINANCIAL ANALYSIS

F-1 ECONOMIC PARAMETERS

The financial analyses for the 8 plant cases being evaluated are calculated assuming the following set of economic parameters:

a. Period of analysis: 1983 to 2000. Fifteen year operating life from 1986 to 2000.

b. B.C. inflation rate: 10% per year throughout total period.

c. Direct capital costs: From Chapters 5 and 6.

d. Schedule of capital costs:

1983	5%
1984	45%
1985	50%

e. Capital cost inflation: 2% per year above the inflation rates.

f. Infrastructure: Project contributions towards such items as housing and community facilities, and road or rail access. Estimated at 1% of capital costs.

g. Start-up costs: Estimated at 5% of direct capital costs for salaries, hiring, moving, and training expenses for staff. One-half in 1985 and one-half in 1986.

h. Working capital: 2.5% of capital cost incurred in 1986 and recaptured in 2000.

i. Capital financing: 50% debt, 50% equity, before calculation of IDC. IDC rolled into long term debt at end of construction period.

j. Interest during construction: Calculated on 50% of debt incurred in current year plus 100% of debt incurred in previous years. Interest rate at 17% for current $ financial analysis.

k. Long term interest rate: 17% for current $ financial analysis.

l. Debt recovery: Debt principal repaid in equal annual installments from year end 1986 to year end 2000, for current $ case.

m. Return on equity: After tax return on equity in current $ financial analysis at 20% per year.

n. Start-up schedule.

60% output in 1986
100% output in 1987 to 2000

o. Days of operation: 330 days/year.

p. Plant Salvage value: Nil.

q. Operating costs: From Chapters 5 and 6.

r. Operating cost inflation: 2% per year above the inflation rates.

s. Feedstock costs, wood supply: From Chapter 3.

t. Feedstock costs, natural gas: Price schedule as per Table F-1a. Multiply by inflation rate forecast for current $ financial analysis.

u. Electric power: Price schedules as per Table F-1b. Multiply by inflation rate forecast for current $ financial analysis.

v. Product prices for methanol, ethanol: Plant site prices are to be calculated from the financial analysis based on the levels that are necessary to provide the specified return to capital.

w. Depreciation: Land and working capital not depreciable. Apply accelerated capital cost allowance (2-yr. st. line) on 80% of depreciable cost; other 20% of cost depreciated at 20% declining balance.

x. Income tax: Corporate income taxes based on a 36% federal rate plus a 16% provincial rate. Taxes are calculated on a stand alone project basis.

y. Sales tax: Use present 6% provincial rate. Applies to industrial sales of natural gas and electricity.

TABLE F-1a

WOOD/ALCOHOL PROJECT

NATURAL GAS PRICE FORECAST

(1982 $/GJ)

	B.C. City Gate Price	Large Industrial Price
1982	2.76	3.26
83	3.16	3.66
84	3.41	3.91
85	3.52	4.02
1986	3.77	4.27
87	4.04	4.54
88	4.32	4.82
89	4.61	5.11
1990	4.92	5.42
1995	6.05	6.55
2000	6.81	7.31

Source: Canadian Resourcecon Ltd.

FOOTNOTES TO TABLE F-1a

(1) The B.C. city gate prices are estimated at 50% of the Canadian crude price at Vancouver until 1985, increasing by 2% per year to 60% of the crude price by 1990, and increasing by 1% per year to 65% of the crude price by 1995; this relationship remains at 65% from 1995 to 2000. This schedule of prices includes the federal excise and the Canadianization levies.

(2) The Vancouver crude oil price to which natural gas prices are related is forecast on the principles continued in the federal/Alberta Energy Pricing Agreement, dated September 1, 1981 (see Table 7-3 in main report). World oil prices, to which Canadian prices are related, are forecast to increase at a real rate of 2% per year to 2000.

(3) The large industrial burner tip price includes a distributor margin of 50¢/GJ above the city gate price.

TABLE F-1b

WOOD/ALCOHOL PROJECT

ELECTRIC ENERGY PRICE FORECAST

	1982 $ Electric Energy Rate	
	¢/kwh	$/GJ
1982	2.50	6.94
83	2.52	7.00
84	2.55	7.08
85	2.58	7.17
1986	2.60	7.22
87	2.63	7.30
88	2.65	7.36
89	2.68	7.44
1990	2.71	7.53
1995	2.85	7.92
2000	2.99	8.31

Source: Canadian Resourcecon Ltd.

Note: 1 kwh = 0.0036 GJ

FOOTNOTES TO TABLE F-1b

(1) Rate for 1982 from B.C. Hydro's "General Service - Transmission" rate (Schedules 1821 and 1899) for a customer with 5000 kw demand and a 75% load factor.

(2) Electric energy price forecast to increase at a real rate (1982 $) of 1% per year.

F-2 FINANCIAL ANALYSIS - BASE CASES

BASE CASE DESCRIPTIONS

CASE #	
1-WO	150 t/d Plant at Williams Lake - wood feedstock - without byproducts
2-WO	150 t/d Ethanol Plant at Kamloops - wood feedstock - without byproducts
3-W	300 t/d Ethanol Plant at Williams Lake - wood feedstock - with byproducts
4-WO	300 t/d Ethanol Plant at Williams Lake - wood feedstock - without byproducts
5	300 t/d Methanol Plant at Williams Lake - wood feedstock
6	300 t/d Methanol Plant at Kamloops - wood feedstock
7	600 t/d Methanol Plant at Williams Lake - wood feedstock
8	990 t/d Methanol Plant at Williams Lake - natural gas/wood feedstock
9	990 t/d Methanol Plant at Williams Lake - natural gas/wood feedstock. Sensitivity case for low crude oil price forecast.

FEEDSTOCK COSTS

CASE #1-WO 150 t/d Ethanol Plant (Williams Lake)

- total plant requirements of 750 ODt/d available at $4.00/ODt
- equal to $20.00/tonne or $15.78/m^3 of ethanol produced

CASE #2-WO 150 t/d Ethanol Plant (Kamloops)

- total plant requirements of 750 ODt/d available at $29.00 /ODt
- equal to $145.00/tonne or $114.44/m^3 of ethanol produced

CASE #3-W 300 t/d Ethanol Plant (Williams Lake)

- 300 000 ODt/yr available at $4.00/ODt and remainder of plant requirements (195 000 ODt/yr) available at $14.00/ODt

- equal to \$39.70/tonne or \$31.33/m^3 of ethanol produced
- during first year of operation at 60% (1986) feedstock cost same as for 150 t/d ethanol plant since only 297 000 ODt/yr required

CASE #4-WO 300 t/d Ethanol Plant (Williams Lake)

- same as CASE #3-W

CASE #5 300 t/d Methanol Plant (Williams Lake)

- total plant requirement available at \$4.00/ODt
- equal to \$9.65/tonne or \$7.64/m^3 of methanol produced

CASE #6 300 t/d Methanol Plant (Kamloops)

- total plant requirements at \$29.00/ODt
- equal to \$69.99/tonne or \$55.37 m^3 of methanol produced

CASE #7 600 t/d Methanol Plant (Williams Lake)

- 300 000 ODt/yr available at \$4.00/ODt and remainder of plant requirements (177 840 ODt/yr) available at \$14.00/ODt
- equal to \$18.63/tonne or \$14.74/m^3 of methanol produced

CASE #8 990 t/d methanol plant (Williams Lake)

- total wood requirements 724 ODt/d at \$4/ODt.
- total gas requirements 4.56 x 10^6 GJ/yr at gas prices detailed in Table F-1a.

CASE #9 990 t/d Methanol Plant (Williams Lake)

- same as Case #8 except with lower natural gas feedstock costs based on low crude oil price forecast case (see Section 7.9).

CASE #1 - WO

150 T/D ETHANOL FROM WOOD (WILLIAMS LAKE)

WITHOUT BY-PRODUCTS

LEVELLIZED PLANT GATE PRICE ESTIMATE

YEAR	PRODUCTION MILLION LITRES/YR	CAPITAL COST EQUITY	CAPITAL COST LONG TERM DEBT	GROSS REVENUES MILLIONS	TOTAL OPERATING COSTS OF	DEBT SERVICE CURRENT	CAPITAL COST ALLOWANCE DOLLARS	INCOME TAXES	CASH FLOW	UNIT REVENUE 1982 $ PER LITRE
1983	0.00	2.50	0.00	0.00	0.00	0.00	0.00	0.00	-2.50	0.00
1984	0.00	25.30	0.00	0.00	0.00	0.00	0.00	0.00	-25.30	0.00
1985	0.00	33.61	71.04	0.00	0.00	0.00	0.00	0.00	-33.61	0.00
1986	37.63	3.20	3.54	32.54	25.00	16.55	58.28	0.00	-12.55	.60
1987	62.72	0.00	0.00	60.46	29.41	16.57	57.93	0.00	14.41	.60
1988	62.72	0.00	0.00	66.45	32.95	15.72	3.96	0.00	17.77	.60
1989	62.72	0.00	0.00	73.08	36.95	14.86	3.17	0.00	21.27	.60
1990	62.72	0.00	0.00	80.39	41.39	14.01	2.53	0.00	24.99	.60
1991	62.72	0.00	0.00	88.42	46.41	13.15	2.03	.04	28.83	.60
1992	62.72	0.00	0.00	97.27	52.03	12.30	1.62	18.30	14.64	.60
1993	62.72	0.00	0.00	106.99	58.29	11.44	1.30	21.32	15.94	.60
1994	62.72	0.00	0.00	117.69	65.38	10.59	1.04	23.78	17.95	.60
1995	62.72	0.00	0.00	129.40	73.20	9.73	.83	26.35	20.12	.60
1996	62.72	0.00	0.00	142.41	82.14	8.88	.66	28.99	22.40	.60
1997	62.72	0.00	0.00	156.65	92.07	8.02	.53	31.75	24.81	.60
1998	62.72	0.00	0.00	172.31	103.21	7.17	.42	34.60	27.34	.60
1999	62.72	0.00	0.00	189.55	115.70	6.31	.34	37.56	29.98	.60
2000	62.72	0.00	0.00	208.50	129.72	5.46	.27	40.60	32.72	.60

SOURCE . CANADIAN RESOURCECON LIMITED

FEB 8/83

SEE APPENDIX F-1 FOR UNDERLYING ECONOMIC PARAMETERS.
DEBT SERVICE IS INTEREST PLUS PRINCIPAL PAYMENT.
CASH FLOW IS CALCULATED AFTER REPAYMENT OF DEBT
PRINCIPAL PLUS INTEREST

150 T/D ETHANOL FROM WOOD (KAMLOOPS)

WITHOUT BY-PRODUCTS

LEVELLIZED PLANT GATE PRICE ESTIMATE

YEAR	PRODUCTION MILLION LITRES/YR	CAPITAL COST EQUITY	CAPITAL COST LONG TERM DEBT	GROSS REVENUES MILLIONS	TOTAL OPERATING COSTS OF	DEBT SERVICE CURRENT	CAPITAL COST ALLOWANCE DOLLARS	INCOME TAXES	CASH FLOW	UNIT REVENUE 1982 $ PER LITRE
1983	0.00	2.50	0.00	0.00	0.00	0.00	0.00	0.00	-2.50	0.00
1984	0.00	25.20	0.00	0.00	0.00	0.00	0.00	0.00	-25.20	0.00
1985	0.00	33.61	71.63	0.00	0.00	0.00	0.00	0.00	-33.61	0.00
1986	37.63	3.26	3.54	38.37	31.09	16.55	58.27	0.00	-12.53	.70
1987	62.72	0.00	0.00	76.35	39.37	16.57	57.91	0.00	20.41	.70
1988	62.72	0.00	0.00	77.38	43.91	15.71	3.96	0.00	17.76	.70
1989	62.72	0.00	0.00	85.12	49.00	14.86	3.17	0.00	21.26	.70
1990	62.72	0.00	0.00	93.63	54.65	14.00	2.55	0.00	24.96	.70
1991	62.72	0.00	0.00	103.60	60.99	13.15	2.03	.64	28.82	.70
1992	62.72	0.00	0.00	115.30	68.67	12.29	1.62	18.90	14.63	.70
1993	62.72	0.00	0.00	124.63	75.34	11.44	1.36	21.31	15.94	.70
1994	62.72	0.00	0.00	137.69	84.79	10.58	1.04	23.77	17.95	.70
1995	62.72	0.00	0.00	150.86	94.61	9.73	.83	26.34	20.12	.70
1996	62.72	0.00	0.00	165.88	105.63	8.87	.66	28.99	22.39	.70
1997	62.72	0.00	0.00	182.47	117.90	8.02	.53	31.74	24.80	.70
1998	62.72	0.00	0.00	200.71	131.62	7.17	.42	34.59	27.33	.70
1999	62.72	0.00	0.00	220.79	146.96	6.31	.34	37.55	29.97	.70
2000	62.72	0.00	0.00	242.86	164.16	5.46	.27	40.59	32.71	.70

SOURCE . CANADIAN RESOURCECON LIMITED

FEB 8/83

SEE APPENDIX F-1 FOR UNDERLYING ECONOMIC PARAMETERS.
DEBT SERVICE IS INTEREST PLUS PRINCIPAL PAYMENT.
CASH FLOW IS CALCULATED AFTER REPAYMENT OF DEBT
PRINCIPAL PLUS INTEREST

300 T/D ETHANOL FROM WOOD (WILLIAMS LAKE)

WITH BY-PRODUCTS

LEVELLIZED PLANT GATE PRICE ESTIMATE

YEAR	PRODUCTION MILLION LITRES/YR	CAPITAL COST		GROSS REVENUES MILLIONS	TOTAL OPERATING COSTS OF	DEBT SERVICE CURRENT	CAPITAL COST ALLOWANCE DOLLARS	INCOME TAXES	CASH FLOW	UNIT REVENUE 1982 $ PER LITRE
		EQUITY	LONG TERM DEBT							
1983	0.00	5.67	0.00	0.00	0.00	0.00	0.00	0.00	-5.67	0.00
1984	0.00	57.21	0.00	0.00	0.00	0.00	0.00	0.00	-57.21	0.00
1985	0.00	74.69	162.03	0.00	0.00	0.00	0.00	0.00	-74.69	0.00
1986	73.26	7.33	0.62	59.26	34.26	37.44	131.64	0.00	-19.78	.54
1987	125.43	0.00	0.00	108.65	42.74	37.49	131.65	0.00	28.41	.54
1988	125.43	0.00	0.00	119.50	47.81	35.56	8.95	0.00	36.13	.54
1989	125.43	0.00	0.00	131.45	53.50	33.62	7.16	0.00	44.32	.54
1990	125.43	0.00	0.00	144.59	59.86	31.69	5.73	0.00	53.04	.54
1991	125.43	0.00	0.00	159.65	66.98	29.75	4.58	0.00	62.92	.54
1992	125.43	0.00	0.00	174.36	74.95	27.82	3.67	36.45	35.73	.54
1993	125.43	0.00	0.00	192.45	83.84	25.89	2.93	47.41	35.32	.54
1994	125.43	0.00	0.00	211.70	93.83	23.95	2.35	53.53	40.38	.54
1995	125.43	0.00	0.00	232.87	105.20	22.62	1.88	59.38	45.67	.54
1996	125.43	0.00	0.00	256.15	117.52	20.08	1.50	66.78	51.77	.54
1997	125.43	0.00	0.00	281.77	131.52	18.15	1.20	73.98	58.11	.54
1998	125.43	0.00	0.00	309.94	147.20	16.21	.96	81.61	64.92	.54
1999	125.43	0.00	0.00	340.94	164.81	14.28	.77	89.68	72.17	.54
2000	125.43	0.00	0.00	375.05	184.46	12.35	.62	98.28	79.95	.54

SOURCE . CANADIAN RESOURCECON LIMITED

FEB 8/83

SEE APPENDIX F-1 FOR UNDERLYING ECONOMIC PARAMETERS.
DEBT SERVICE IS INTEREST PLUS PRINCIPAL PAYMENT.
CASH FLOW IS CALCULATED AFTER REPAYMENT OF DEBT
PRINCIPAL PLUS INTEREST

CASE #4 - WO

200 T/D ETHANOL FROM WOOD (WILLIAMS LAKE)

WITHOUT BY-PRODUCTS

LEVELLIZED PLANT GATE PRICE ESTIMATE

YEAR	PRODUCTION MILLION LITRES/YR	CAPITAL COST EQUITY	CAPITAL COST LONG TERM DEBT	GROSS REVENUES MILLIONS OF	TOTAL OPERATING COSTS	DEBT SERVICE CURRENT	CAPITAL COST ALLOWANCE DOLLARS	INCOME TAXES	CASH FLOW	UNIT REVENUE 1982 $ PER LITRE
1983	0.00	3.86	0.00	0.00	0.00	0.00	0.00	0.00	-3.86	0.00
1984	0.00	38.33	0.00	0.00	0.00	0.00	0.00	0.00	-38.33	0.00
1985	0.00	49.58	108.16	0.00	0.00	0.00	0.00	0.00	-49.58	0.00
1986	75.26	3.96	4.38	55.87	42.51	24.37	87.91	0.00	-17.58	.49
1987	125.43	0.00	0.00	98.76	52.68	24.76	87.17	0.00	21.32	.49
1988	125.43	0.00	0.00	108.63	58.29	23.48	5.80	0.00	26.86	.49
1989	125.43	0.00	0.00	119.49	65.25	22.20	4.64	0.00	32.04	.49
1990	125.43	0.00	0.00	131.44	73.04	20.92	3.71	0.00	37.47	.49
1991	125.43	0.00	0.00	144.59	81.76	19.65	2.97	.21	42.96	.49
1992	125.43	0.00	0.00	159.05	91.52	18.37	2.38	28.23	20.92	.49
1993	125.43	0.00	0.00	174.35	102.47	17.09	1.90	31.72	23.07	.49
1994	125.43	0.00	0.00	192.45	114.73	15.82	1.52	35.31	26.60	.49
1995	125.43	0.00	0.00	211.63	128.45	14.54	1.22	39.00	29.71	.49
1996	125.43	0.00	0.00	232.86	143.83	13.26	.97	42.80	32.97	.49
1997	125.43	0.00	0.00	256.15	161.06	11.98	.78	46.72	36.39	.49
1998	125.43	0.00	0.00	281.76	186.33	10.71	.62	50.76	33.96	.49
1999	125.43	0.00	0.00	309.94	201.96	9.43	.50	54.89	43.66	.49
2000	125.43	0.00	0.00	340.93	226.15	8.15	.40	59.14	47.48	.49

SOURCE . CANADIAN RESOURCECON LIMITED

FEB 8/83

SEE APPENDIX F-1 FOR UNDERLYING ECONOMIC PARAMETERS.
DEBT SERVICE IS INTEREST PLUS PRINCIPAL PAYMENT.
CASH FLOW IS CALCULATED AFTER REPAYMENT OF DEBT
PRINCIPAL PLUS INTEREST

CASE #5

100 T/D METHANOL FROM WOOD

WILLIAMS LAKE

LEVELLIZED PLANT GATE PRICE ESTIMATE

YEAR	PRODUCTION MILLION LITRES/YR	CAPITAL COST		GROSS REVENUES	TOTAL OPERATING COSTS	DEBT SERVICE	CAPITAL COST ALLOWANCE	INCOME TAXES	CASH FLOW	UNIT REVENUE 1982 $ PER LITRE
		EQUITY	LONG TERM DEBT	MILLIONS	OF	CURRENT	DOLLARS			
1983	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	-2.00	0.00
1984	0.00	20.34	0.00	0.00	0.00	0.00	0.00	0.00	-20.34	0.00
1985	0.00	27.36	53.35	0.00	0.00	0.00	0.00	0.00	-27.36	0.00
1986	75.00	2.71	2.34	26.00	20.22	13.71	48.28	0.00	-10.64	.24
1987	125.14	0.00	0.00	48.76	23.27	13.73	47.99	0.00	11.76	.24
1988	125.14	0.00	0.00	53.64	26.08	13.62	3.28	0.00	14.54	.24
1989	125.14	0.00	0.00	59.00	29.25	12.31	2.62	0.00	17.46	.24
1990	125.14	0.00	0.00	64.90	32.76	11.60	2.10	0.00	20.54	.24
1991	125.14	0.00	0.00	71.39	36.72	10.90	1.68	0.00	23.78	.24
1992	125.14	0.00	0.00	78.53	41.14	10.19	1.34	15.39	11.81	.24
1993	125.14	0.00	0.00	86.38	46.11	9.48	1.07	17.62	13.17	.24
1994	125.14	0.00	0.00	95.02	51.66	8.77	.86	19.71	14.88	.24
1995	125.14	0.00	0.00	104.53	57.90	8.00	.69	21.86	16.76	.24
1996	125.14	0.00	0.00	114.98	64.90	7.35	.55	24.16	18.63	.24
1997	125.14	0.00	0.00	126.48	72.73	6.65	.44	26.43	20.67	.24
1998	125.14	0.00	0.00	139.12	81.52	5.94	.35	28.85	22.82	.24
1999	125.14	0.00	0.00	153.04	91.34	5.23	.28	31.38	25.08	.24
2000	125.14	0.00	0.00	168.34	102.42	4.52	.23	33.98	27.42	.24

SOURCE . CANADIAN RESOURCECON LIMITED

FEB 8/83

SEE APPENDIX F-1 FOR UNDERLYING ECONOMIC PARAMETERS.
DEBT SERVICE IS INTEREST PLUS PRINCIPAL PAYMENT.
CASH FLOW IS CALCULATED AFTER REPAYMENT OF DEBT
PRINCIPAL PLUS INTEREST

CASE #6

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300 T/D METHANOL FROM WOOD

KAMLOOPS

LEVELLIZED PLANT GATE PRICE ESTIMATE

YEAR	PRODUCTION MILLION LITRES/YR	CAPITAL COST EQUITY	CAPITAL COST LONG TERM DEBT	GROSS REVENUES	TOTAL OPERATING COSTS	DEBT SERVICE	CAPITAL COST ALLOWANCE	INCOME TAXES	CASH FLOW	UNIT REVENUE 1982 $ PER LITRE
				MILLIONS OF CURRENT DOLLARS						
1983	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	-2.00	0.00
1984	0.00	20.34	0.00	0.00	0.00	0.00	0.00	0.00	-20.34	0.00
1985	0.00	27.30	59.55	0.00	0.00	0.00	0.00	0.00	-27.30	0.00
1986	75.08	2.71	2.34	31.85	25.47	15.71	48.28	0.00	-10.64	.29
1987	125.14	0.00	0.00	58.40	32.91	15.73	47.39	0.00	11.76	.29
1988	125.14	0.00	0.00	64.24	36.00	15.62	3.28	0.00	14.54	.29
1989	125.14	0.00	0.00	70.66	40.89	12.31	2.62	0.00	17.46	.29
1990	125.14	0.00	0.00	77.72	45.58	11.66	2.16	0.00	20.54	.29
1991	125.14	0.00	0.00	85.50	50.82	10.36	1.68	0.00	22.78	.29
1992	125.14	0.00	0.00	94.05	56.05	10.13	1.34	15.39	11.61	.29
1993	125.14	0.00	0.00	103.45	65.18	9.48	1.07	17.62	12.17	.29
1994	125.14	0.00	0.00	113.80	76.43	8.77	.86	19.71	14.88	.29
1995	125.14	0.00	0.00	125.18	78.55	8.06	.69	21.86	16.76	.29
1996	125.14	0.00	0.00	137.69	87.62	7.35	.55	24.16	18.63	.29
1997	125.14	0.00	0.00	151.46	97.72	6.65	.44	26.43	20.67	.29
1998	125.14	0.00	0.00	166.61	109.61	5.94	.35	28.65	22.82	.29
1999	125.14	0.00	0.00	183.27	121.57	5.25	.28	31.38	25.08	.29
2000	125.14	0.00	0.00	201.60	135.08	4.52	.23	33.98	27.42	.29

SOURCE . CANADIAN RESOURCECON LIMITED

FEB 8/83

SEE APPENDIX F-1 FOR UNDERLYING ECONOMIC PARAMETERS.
DEBT SERVICE IS INTEREST PLUS PRINCIPAL PAYMENT.
CASH FLOW IS CALCULATED AFTER REPAYMENT OF DEBT
PRINCIPAL PLUS INTEREST

CASE #7

600 T/D METHANOL FROM WOOD

WILLIAMS LAKE

LEVELLIZED PLANT GATE PRICE ESTIMATE

YEAR	PRODUCTION MILLION LITRES/YR	CAPITAL COST EQUITY	CAPITAL COST LONG TERM DEBT	GROSS REVENUES	TOTAL OPERATING COSTS	DEBT SERVICE	CAPITAL COST ALLOWANCE	INCOME TAXES	CASH FLOW	UNIT REVENUE 1982 $ PER LITRE
				MILLIONS OF CURRENT DOLLARS						
1983	0.00	3.23	0.00	0.00	0.00	0.00	0.00	0.00	-3.23	0.00
1984	0.00	32.00	0.00	0.00	0.00	0.00	0.00	0.00	-32.00	0.00
1985	0.00	42.64	92.52	0.00	0.00	0.00	0.00	0.00	-42.64	0.00
1986	136.16	4.22	4.58	45.83	32.00	21.37	75.26	0.00	-14.51	.20
1987	256.27	0.00	0.00	80.44	40.64	21.46	74.81	0.00	18.26	.20
1988	256.27	0.00	0.00	88.48	45.70	20.30	5.11	0.00	22.46	.20
1989	256.27	0.00	0.00	97.33	51.13	19.19	4.09	0.00	27.01	.20
1990	256.27	0.00	0.00	107.07	57.21	18.09	3.27	0.00	31.77	.20
1991	256.27	0.00	0.00	117.77	64.02	16.98	2.62	0.00	36.77	.20
1992	256.27	0.00	0.00	129.55	71.64	15.88	2.09	23.84	18.19	.20
1993	256.27	0.00	0.00	142.50	80.17	14.78	1.67	27.24	20.32	.20
1994	256.27	0.00	0.00	156.75	89.72	13.67	1.34	30.43	22.93	.20
1995	256.27	0.00	0.00	172.43	100.42	12.57	1.07	33.73	25.71	.20
1996	256.27	0.00	0.00	189.67	112.36	11.46	.86	37.17	28.67	.20
1997	256.27	0.00	0.00	208.64	125.77	10.36	.69	40.72	31.78	.20
1998	256.27	0.00	0.00	229.50	140.79	9.26	.55	44.41	35.05	.20
1999	256.27	0.00	0.00	252.45	157.59	8.15	.44	48.24	38.47	.20
2000	256.27	0.00	0.00	277.70	176.41	7.05	.35	52.20	42.04	.20

SOURCE . CANADIAN RESOURCECON LIMITED

FEB 8/83

SEE APPENDIX F-1 FOR UNDERLYING ECONOMIC PARAMETERS.
DEBT SERVICE IS INTEREST PLUS PRINCIPAL PAYMENT.
CASH FLOW IS CALCULATED AFTER REPAYMENT OF DEBT
PRINCIPAL PLUS INTEREST

CASE #8

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930 T/D METHANOL FROM WOOD / NATURAL GAS

WILLIAMS LAKE

LEVELLIZED PLANT GATE PRICE ESTIMATE

YEAR	PRODUCTION MILLION LITRES/YR	CAPITAL COST		GROSS REVENUES	TOTAL OPERATING COSTS	DEBT SERVICE	CAPITAL COST ALLOWANCE	INCOME TAXES	CASH FLOW	UNIT REVENUE 1982 $ PER LITRE
		EQUITY	LONG TERM DEBT	MILLIONS	OF	CURRENT	DOLLARS			
1983	0.00	3.90	0.00	0.00	0.00	0.00	0.00	0.00	-3.90	0.00
1984	0.00	39.37	0.00	0.00	0.00	0.00	0.00	0.00	-39.37	0.00
1985	0.00	31.40	111.54	0.00	0.00	0.00	0.00	0.00	-31.40	0.00
1986	247.77	3.10	3.33	71.94	35.17	25.77	30.73	0.00	-14.10	.20
1987	412.35	0.00	0.00	131.89	76.46	25.80	30.19	0.00	29.61	.20
1988	412.35	0.00	0.00	145.07	87.52	24.47	6.16	0.00	33.09	.20
1989	412.35	0.00	0.00	159.58	99.79	23.14	4.93	0.00	36.65	.20
1990	412.35	0.00	0.00	175.54	114.03	21.81	3.94	0.00	39.70	.20
1991	412.35	0.00	0.00	193.09	129.10	20.46	3.16	10.96	32.55	.20
1992	412.35	0.00	0.00	212.40	146.21	19.15	2.52	27.22	19.82	.20
1993	412.35	0.00	0.00	233.64	163.43	17.82	2.02	29.23	21.17	.20
1994	412.35	0.00	0.00	257.01	186.91	16.48	1.62	31.11	22.30	.20
1995	412.35	0.00	0.00	282.71	211.37	15.15	1.29	32.61	23.57	.20
1996	412.35	0.00	0.00	310.38	237.38	13.82	1.03	34.00	25.20	.20
1997	412.35	0.00	0.00	342.08	266.55	12.49	.83	36.42	26.62	.20
1998	412.35	0.00	0.00	376.28	299.37	11.16	.66	37.92	27.83	.20
1999	412.35	0.00	0.00	415.31	336.69	9.83	.53	39.15	28.84	.20
2000	412.35	0.00	0.00	455.30	377.04	8.50	.42	40.13	29.63	.20

SOURCE . CANADIAN RESOURCECON LIMITED

FEB 8/83

SEE APPENDIX F-1 FOR UNDERLYING ECONOMIC PARAMETERS.
DEBT SERVICE IS INTEREST PLUS PRINCIPAL PAYMENT.
CASH FLOW IS CALCULATED AFTER REPAYMENT OF DEBT
PRINCIPAL PLUS INTEREST

CASE #9

330 T/D METHANOL FROM WOOD/NATURAL GAS (WILLIAMS LAKE)

LOW NATURAL GAS PRICE FORECAST

LEVELLIZED PLANT GATE PRICE ESTIMATE

YEAR	PRODUCTION MILLION LITRES/YR	CAPITAL COST EQUITY	CAPITAL COST LONG TERM DEBT	GROSS REVENUES MILLIONS	TOTAL OPERATING COSTS OF	DEBT SERVICE CURRENT	CAPITAL COST ALLOWANCE DOLLARS	INCOME TAXES	CASH FLOW	UNIT REVENUE 1982 $ PER LITRE
1983	0.00	3.90	0.00	0.00	0.00	0.00	0.00	0.00	-3.90	0.00
1984	0.00	33.37	0.00	0.00	0.00	0.00	0.00	0.00	-33.37	0.00
1985	0.00	31.40	111.54	0.00	0.00	0.00	0.00	0.00	-31.40	0.00
1986	247.77	5.10	5.53	63.37	49.95	25.77	90.73	0.00	-17.44	.17
1987	412.95	0.00	0.00	116.17	65.84	25.80	90.13	0.00	24.54	.17
1988	412.95	0.00	0.00	127.79	74.05	24.47	6.10	0.00	29.27	.17
1989	412.95	0.00	0.00	140.57	83.38	23.14	4.93	0.00	34.05	.17
1990	412.95	0.00	0.00	154.63	93.76	21.61	3.34	0.00	39.06	.17
1991	412.95	0.00	0.00	170.69	105.31	20.48	3.10	3.30	41.60	.17
1992	412.95	0.00	0.00	187.16	118.25	19.15	2.32	28.60	21.16	.17
1993	412.95	0.00	0.00	205.81	132.56	17.82	2.02	31.85	23.59	.17
1994	412.95	0.00	0.00	226.39	148.20	16.48	1.62	33.61	28.10	.17
1995	412.95	0.00	0.00	249.63	167.64	15.15	1.29	38.16	28.68	.17
1996	412.95	0.00	0.00	273.93	186.49	13.82	1.03	41.82	31.80	.17
1997	412.95	0.00	0.00	301.33	206.59	12.49	.83	45.37	36.88	.17
1998	412.95	0.00	0.00	331.46	232.96	11.16	.66	49.14	38.19	.17
1999	412.95	0.00	0.00	364.60	260.53	9.83	.53	52.80	41.44	.17
2000	412.95	0.00	0.00	401.06	290.95	8.50	.42	56.69	44.93	.17

SOURCE . CANADIAN RESOURCECON LIMITED

FEB 8/83

SEE APPENDIX F-1 FOR UNDERLYING ECONOMIC PARAMETERS.
DEBT SERVICE IS INTEREST PLUS PRINCIPAL PAYMENT.
CASH FLOW IS CALCULATED AFTER REPAYMENT OF DEBT
PRINCIPAL PLUS INTEREST

APPENDIX G

STATUS OF ALCOHOL FUEL USE IN MOTOR VEHICLES

APPENDIX G

STATUS OF ALCOHOL FUEL USE IN MOTOR VEHICLES (DECEMBER 1982)

(a) Factory Built Vehicles for Mono-Fuel Operation

Factory built methanol and ethanol vehicles have engines with higher compression ratios than gasoline engines, and careful attention to non-corrodable metals and alcohol-tolerant elastomers, plastics and gasket materials throughout the fuel system. Carburetor jets are larger than for gasoline as greater volumetric fuel delivery is required, and for equal range a larger fuel tank is required than for gasoline. For optimal performance, an engine and fuel system would be tailored to either ethanol or methanol. However, in practical terms, a vehicle designed to use methanol (more corrosive than ethanol) could readily be converted to ethanol by modifying carburetor jets or recalibrating injectors. Conversely, a vehicle designed for ethanol could readily be built to allow for future modification to methanol.

To date, neat alcohol fuels often contain 5 to 10 or more percent of other hydrocarbon liquids such as gasoline or iso-pentane. These liquids are added to improve volatility for cold starting (10 to 15°C is the upper end of the "cold" range), to provide lubrication and to denature the alcohol.

Brazil is the leader in alcohol fuels, with several hundred thousand factory built units on neat ethanol. A number of North American and European manufacturers have experimented with alcohol fuel vehicles to the point of proving technical viability, and identifying potential problem areas. Currently, in the United States, Ford is building 560 methanol-fueled Escorts to fill a government order coordinated by the California Energy Commission, and an additional 250 units for speculative sale to other fleet buyers. These will supplement some 60 methanol and 20 ethanol autos and pickups (Volkswagens and Escorts) which are already in government service in California. In Canada, Canadian Methanol is using methanol in Winnipeg in a small test fleet of Volkswagens and Toyotas (retrofit?), and anticipates adding some Escorts.

(b) Retrofit Gasoline Vehicles to Methanol or Ethanol

Most conversions to date have been to achieve monofuel alcohol operation, though technology is at the road test stage to allow switching between gasoline and alcohol (larger carburetor jets must be brought into operation for alcohols). Typically, conversions involve substitution of alcohol tolerant materials throughout the fuel system, and carburetor modifications. While steps may be taken to raise compression ratios, one major conversion centre (Future Fuels of America, California) states that the cost is not justifiable.

North American interest in retrofitting to alcohols is centred in California, and methanol is the favoured fuel. A number of fleets operate converted vehicles. The Bank of America has the most experience with 266 vehicles on methanol; other users include Fireman's Fund Insurance, Pacific Bell, Pacific Gas and Electric, and Hughes Aircraft. In Canada, Canadian Methanol have a few cars in Winnipeg, including two dual-fuel (gasoline or methanol) Toyotas. Mohawk has some operating experience in Edmonton using ethanol.